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February 1989
Volume 13 Number 2

## Ceramics Drive Turbine-Powered Tomorrow

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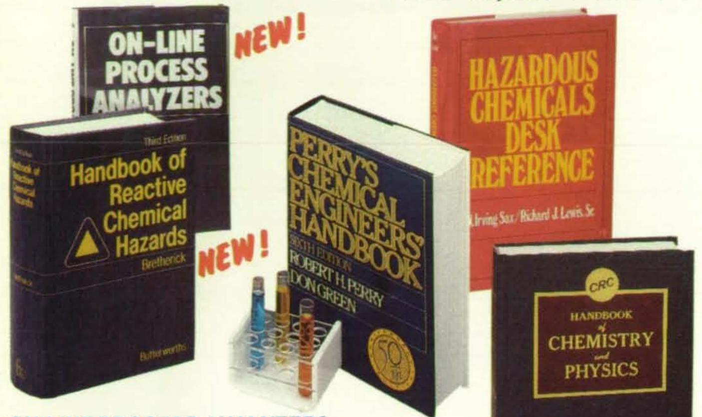


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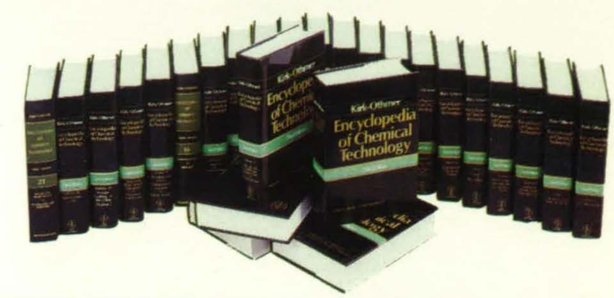

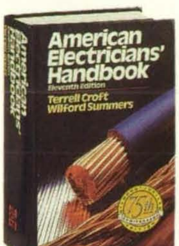


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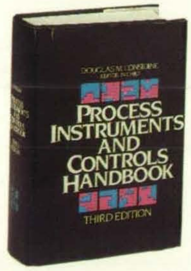


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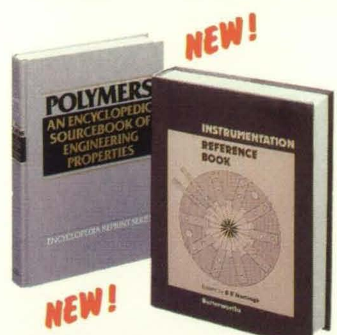


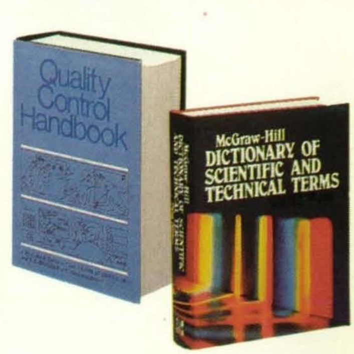


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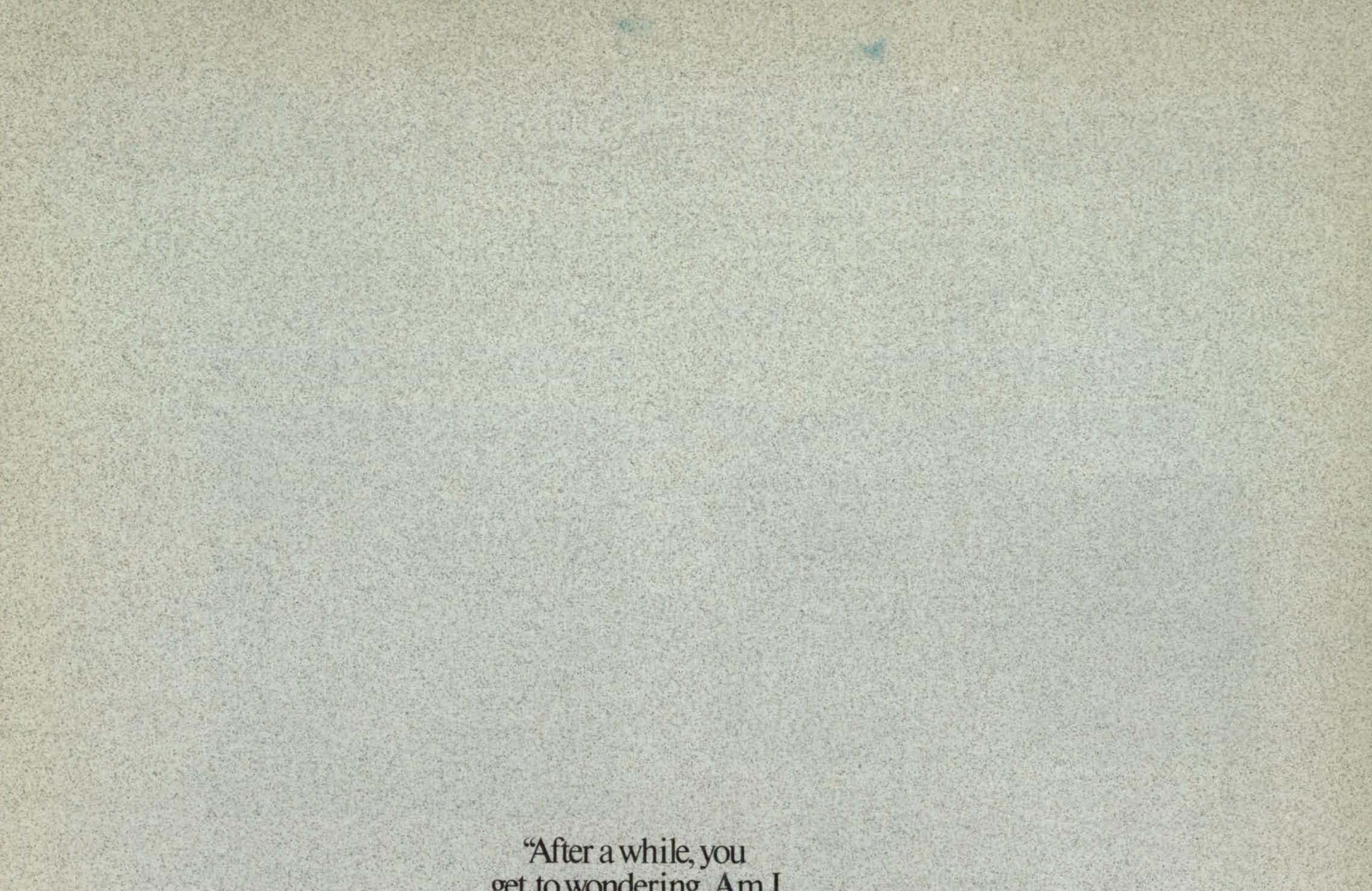
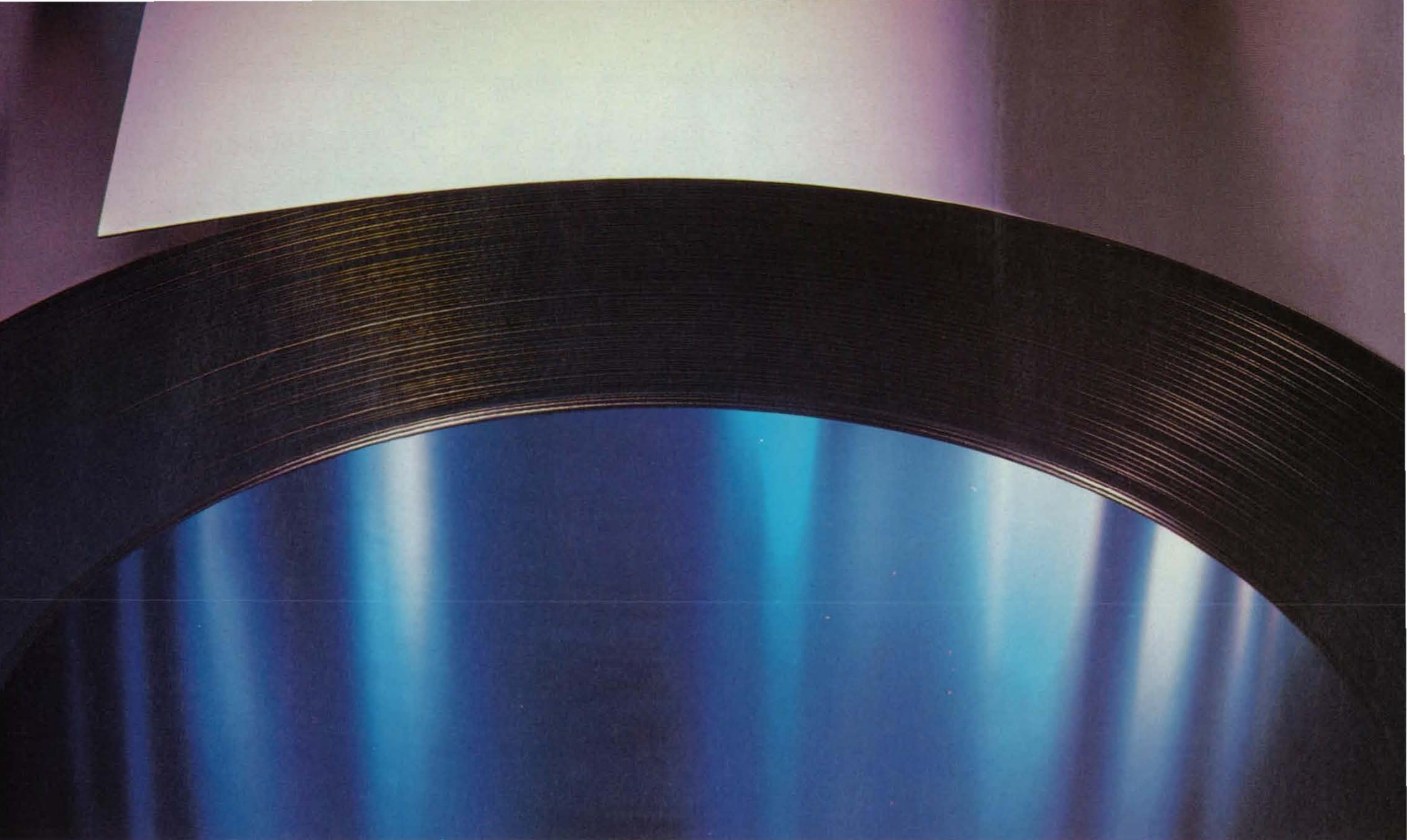
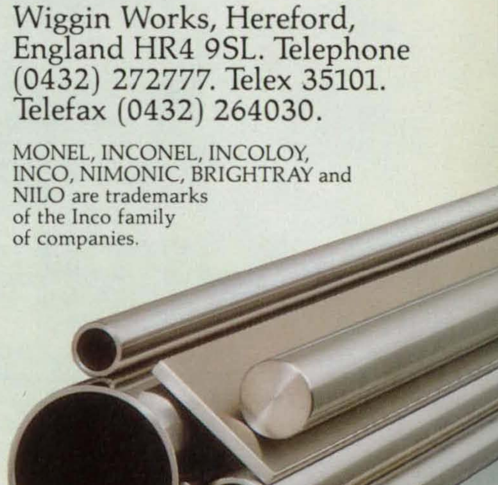

"After a while, you get to wondering. Am I experimenting with it? Or is it experimenting with me?"







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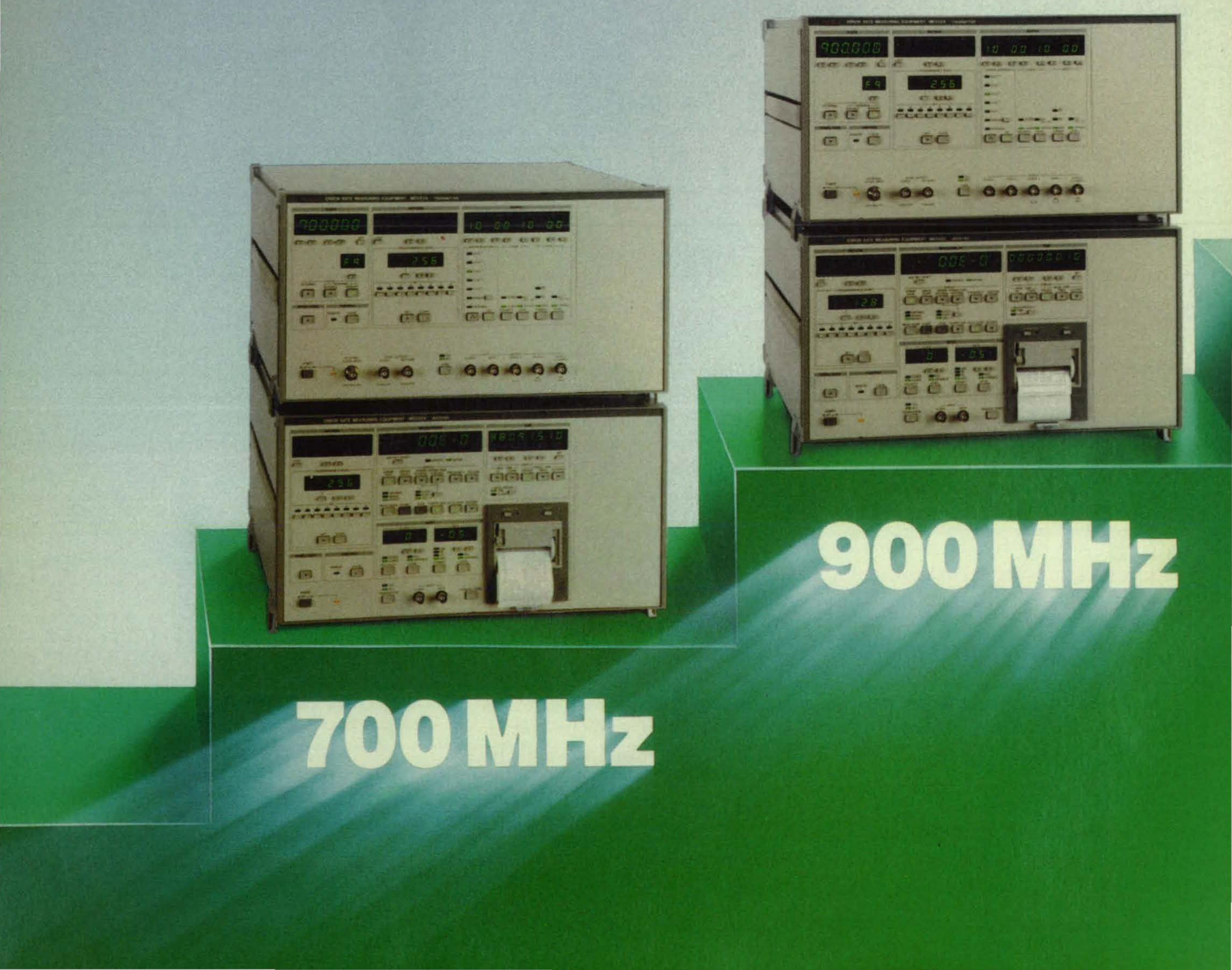


# NASA Tech Briefs

National Aeronautics and
Space Administration

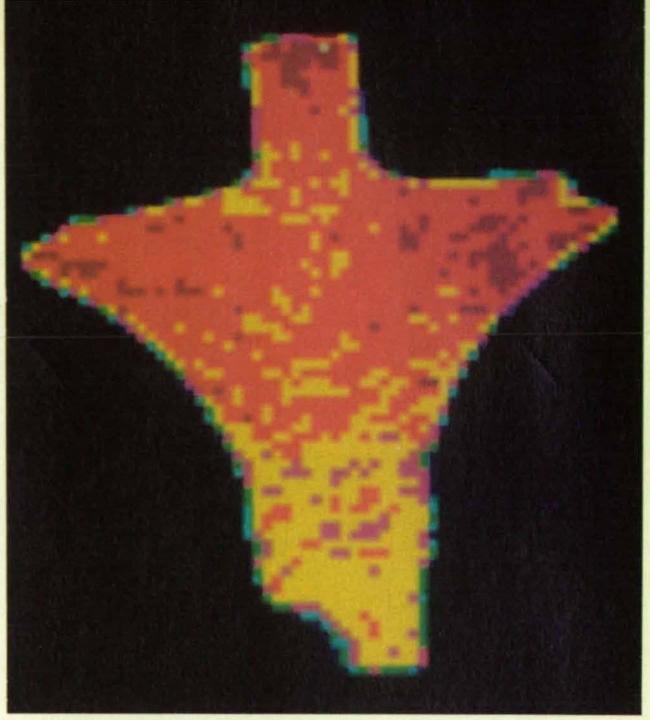
FEBRUARY 1989
Volume 13 Number 2


## SPECIAL FEATURES



## TECHNICAL SECTION





***X-ray computed tomography is used here to detect slight density variations in a turbine engine rotor. This non-destructive evaluation technique will play a key part in a new government/industry research program which aims to advance ceramic engine technology in the U.S. See page 12.*** *(Photo courtesy the Carborundum Company)*

## DEPARTMENTS

***On The Cover: The center illustration shows the Chevrolet Express, an experimental vehicle powered by the General Motors AGT-5 gas turbine engine. The AGT-5 will serve as a test bed for high-strength ceramic engine parts developed during the Advanced Turbine Technology Applications Project (ATTAP), a NASA-managed research effort described on page 12.***

***The outer photo displays thermal shock testing of a ceramic turbine rotor at temperatures approaching 1149°C. ATTAP will evaluate ceramic components at even higher levels—up to 1371°C.*** *(Illustration of Chevrolet Express courtesy the Allison Gas Turbine Div. of the General Motors Corp.)*



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# ATTAP: Shaping

A nationwide team of researchers is creating a tough new breed of structural ceramics capable of surviving the crushing heat and stress within an automobile engine. Their efforts—part of the five-year Advanced Turbine Technology Applications Project (ATTAP)—will provide a technology base for commercial development of ceramic gas turbine engines, envisioned as one day replacing conventional piston power plants in cars and trucks.

Ceramic gas turbines could reduce automobile weight and improve fuel efficiency, while also eliminating dependence on foreign-sourced strategic materials such as titanium and cobalt. Improved corrosion/wear resistance, reduced exhaust emissions, low vibration, and multi-fuel capability are further benefits the ceramic engine would offer.

Sponsored by the Department of Energy and managed by NASA's Lewis Research Center, ATTAP builds on the pioneering work of the Automotive Gas Turbine (AGT) program which ran from October 1979 through June 1987. Engines with ceramic parts were operated successfully for over 250 hours during the program, including an 85-hour test of an all-ceramic hot section at 1204 degrees Celsius and 100,000 rpm rotor speed.

"The AGT program proved the feasibility of a ceramic gas turbine engine," said Robert Evans, Manager of the Terrestrial Propulsion Office at NASA Lewis. "It also pointed out a number of technology challenges in the design, fabrication, and testing of structural ceramics that must be answered before the U.S. automotive industry can reasonably commit to full-scale development."

ATTAP's two contractor teams—headed by the Garrett Auxiliary Power Division of the Allied-Signal Aerospace Company and General Motors' Allison Gas Turbine Division—are taking up the challenge by developing analytical tools for ceramic component design, refining processing and manufacturing methods, and perfecting nondestructive evaluation techniques. To generate a greater fund of knowledge, ATTAP participants will fabricate parts for two types of test beds: the Garrett AGT101 single-shaft, radial-inflow engine, and the Allison AGT-5 two-shaft, axial-flow engine. The project will culminate with 400 hours of engine durability tests at temperatures up to 1371°C to verify the technologies developed.

**Design Tools**

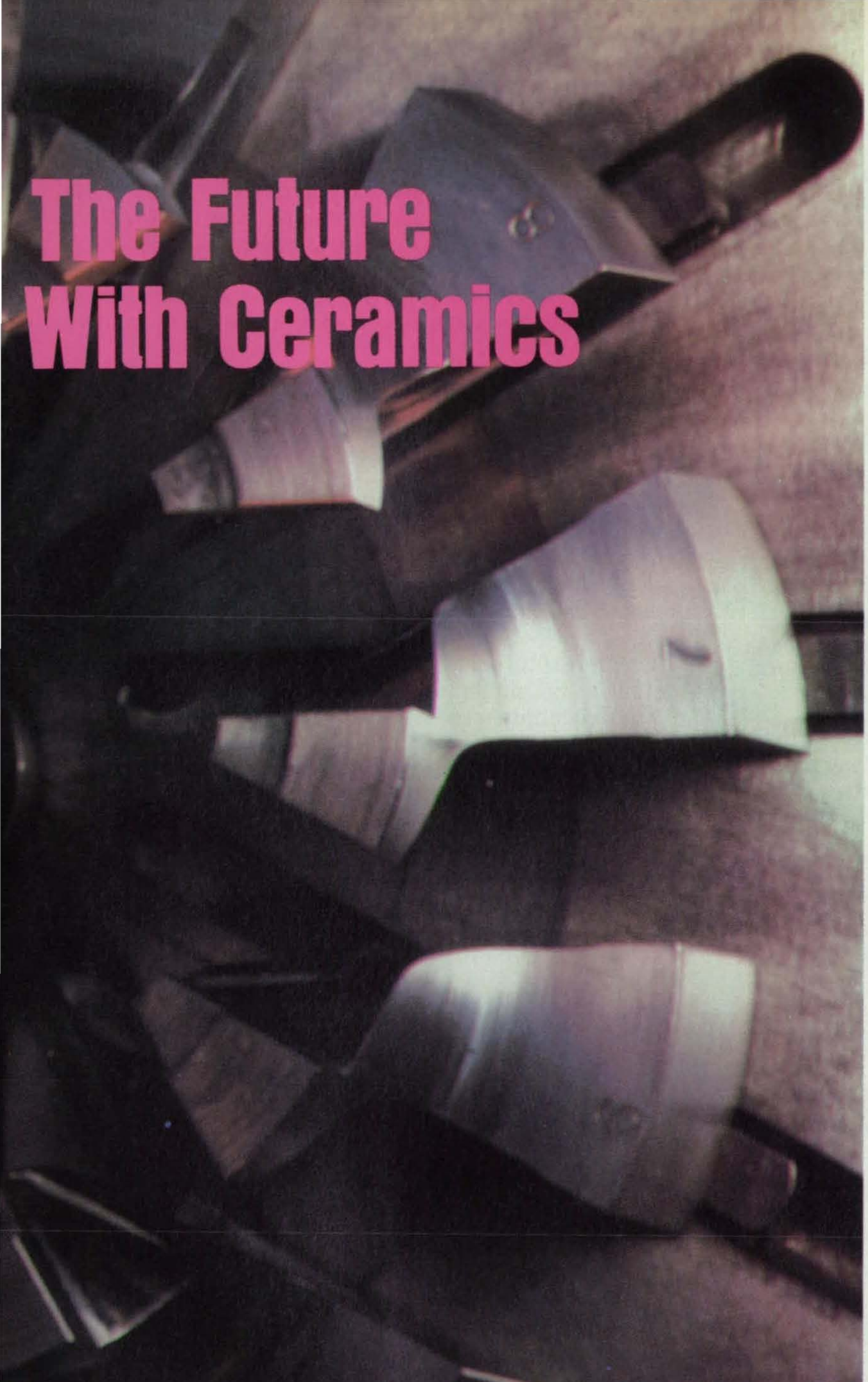
ATTAP researchers are forming life-predictive design methods in the critical areas of impact, contact, and thermoelastic behavior of ceramic materials and parts. If ceramic engines are ever to be a viable commercial product, design engineers must overcome the problem of foreign object impact damage. Tiny particles entering the turbine inlet flowpath can wreak havoc on the rotor and stator, slashing engine life drastically. A two-year study at the University of Dayton Research Institute will measure the damage threshold of ceramics chosen for ATTAP and create algorithms for projecting impact damage. "The study results will provide tools for designing engine parts that have increased impact tolerance," explained Evans.

**Getting Into Shape**

The advanced ceramics selected for ATTAP are very hard materials—an important attribute in fighting wear. This means, however, that grinding is costly and time-consuming. To reduce machine time in the green (unsintered) state, ATTAP contractors will utilize, where practical, net shape forming methods such as injection molding and extrusion. "Through refinement of these forming techniques," stated Evans, "we hope to achieve parts that could be economically and reliably mass-produced for car engines."

Four materials suppliers are developing fabrication methods for the

# The Future With Ceramics



***Left: An injection-molded silicon nitride turbine rotor produced for the Advanced Gas Turbine (AGT) program. Experience gained in that program provides the basis for current ATTAP activities.***
(Photo courtesy GTE Laboratories Inc.)

turbine rotor, considered the engine's critical component because of its high temperature requirements, geometric complexity, and susceptibility to impact damage. Both the Garrett Ceramic Components Division and Norton/TRW Ceramics are experimenting with pressure slip casting of fracture-resistant silicon nitride materials for radial turbine rotors. The latter company is also applying Taguchi-based design methods to powder beneficiation, dewaxing, hot isostatic pressing (HIP), and other process areas.

Rotor development activity at GTE Laboratories has two objectives: to improve injection molding techniques for axial turbine rotors and to toughen silicon nitride material systems by applying silicon carbide whisker reinforcement. Tests have shown that this composite material can be successfully densified by hot isostatic pressing, with a resultant increase in strength.

The Carborundum Company's Structural Ceramics Division plans to form axial rotors through injection molding of Hexoloy® SA, a sintered alpha silicon carbide material that is widely used for seal rings in car water pumps. Carborundum researchers are conducting analytical modeling of the plastic forming process to improve the consistency of both the rotor structure and the injection molding process.

Other engine parts selected for development in ATTAP include:

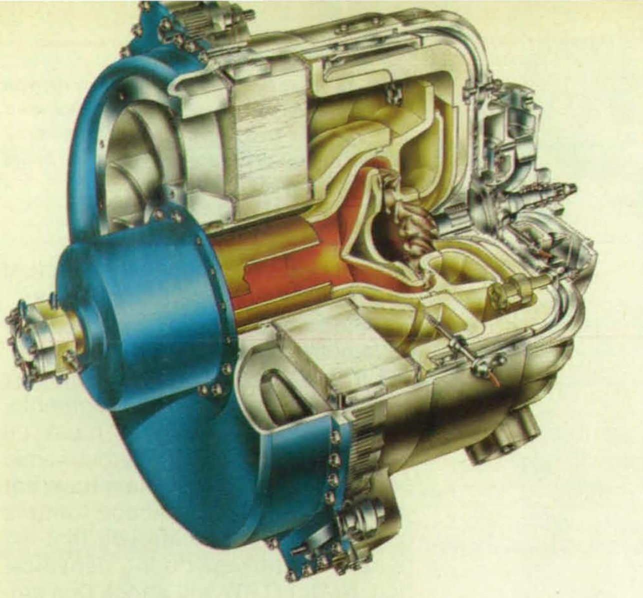
**Turbine Stator.** Another complex shape, the stator has 19 segments, each with contours that must be precisely controlled for aerodynamic performance. U.S. suppliers have not yet demonstrated net shape forming of the stator with materials that experience shrinkage during densification. Norton/TRW will attack this problem with HIPed silicon nitride (HSN). "Dimensional control could be attained in HSN through a thorough understanding of shrinkage rates, residual stress, forming stresses, and control of densification schedules and hot zone temperature variation," said Bryan McEntire, Operations Manager for Norton/TRW Ceramics.

**Ceramic Wave Spring.** Carborundum is developing a process in which thin sheets of Hexoloy SA are extruded and then stamped into shape. Maintaining the spring's sinusoidal wave form during densification will require creative furnace supports and precisely controlled hot zone temperatures, coupled with a homogenous green density free of minute residual stresses that could occur during green forming.

**Transition Duct.** Injection molding of silicon nitride will be used to produce the transition duct, which derives its name from the transition of hot gas flow from the combustor discharge to the larger diameter turbine stator inlet.

**Turbine Backshroud.** This highly stressed part will require a new type of reinforced ceramic to work reliably at the elevated temperatures proposed for ATTAP testing. Carborundum's experiments involve ram pressing of Hexoloy ST, a silicon carbide toughened by dispersed particles of titanium diboride. Fifty percent stronger than direct sintered silicon carbide, Hexoloy ST offers the bonus of being electro-discharge machinable. This stock removal technique could significantly reduce the cost of a final component when coupled to net shape forming development.

**Ceramic Scroll Assembly.** Efforts here are directed toward slip casting of Hexoloy SA. Carborundum is performing statistically designed processing matrices to evaluate the effects of starting powders and slip processing on component castability and process yield.



*The AGT101 regenerated gas turbine engine will serve as a test bed for ceramic rotors, stators, transition ducts, wave springs, and turbine backshrouds developed by ATTAP subcontractors.*

**Regenerator Disk.** Corning Glass Works is researching ways to extrude alumino-silicate regenerator disks for the AGT-5. The extrusion process should vastly improve uniformity, strength, and cost relative to the spiral wrapping methods developed for metal turbines.

### The Ultimate Test

Nondestructive evaluation (NDE) methods such as x-ray computed tomography, optical holography, and nuclear magnetic resonance imaging will play a central role in both quality assurance and process refinement during ATTAP. "We're not just using (NDE) techniques to detect flaws in the finished parts, but rather to improve each step in the fabrication process," said Dr. Truett Sweeting, Technical Manager for Carborundum's Structural Ceramics Division. "For instance, we can use tomography to look at an injection-molded rotor in the green state and find out where the density variations are, then go back and change the molding parameters or make other adjustments to improve consistency."

Voids, iron wires, and other seeded defects will be placed in select materials to determine resolution and detection limits for current NDE techniques, as well as to examine the potential of new testing technologies.

Trial by fire—destructive evaluation of finished parts in test rigs and engine test beds—is slated for 1991-92. The rigs will be used in part to evaluate components under conditions that are predicted to cause failure. Subsequent analysis will correlate fracture origins with peak stress locations and determine if design and/or process modifications are needed.

ATTAP results will be summarized in a Ceramic Design Manual to be published at program's end in 1992. The manual will contain verified design methods and material characterizations to help U.S. industry adapt the new technology in a variety of applications. NASA hopes to use ATTAP innovations to develop high-temperature parts for Space Station and other future spacecraft.

"Even if ceramic gas turbines never reach the marketplace," said Dr. Sweeting, "ATTAP will still be successful by advancing the state of ceramics technology in this country, and thereby helping U.S. materials companies to keep pace with growing foreign competition." □

# Still Crazy After All These Years.


**1946**
When the David Sarnoff Research Center was working on color TV in the early 1940's, people may have thought, "That's crazy!" Yet, in '46 we publicly demonstrated a practical, all-electronic compatible color TV system. It was accepted as the industry standard in 1953, and is still used today.

**1955-'86**
Is it outrageous to work with an Emmy-award winning research center? The fact is, we've won *two* Emmys over the years for bringing new technology into the home: one in 1955 for the tri-color picture tube and another in 1986 for stereo TV. Today, we're advancing audio, video and computer technologies that may become the fully integrated home information center of the future.

**1964**
In the 1950's, the concept of low-power, high-speed integrated circuits a few thousandths of a square inch in size existed only in science fiction, and the laboratory. But in 1964, we introduced the first complementary metal oxide semiconducting chip. Then demonstrated its marketplace value by building the first CMOS 8-bit microprocessor.

**1986**
Was it preposterous of us to try to reproduce the power of a room-sized laser in a smaller unit? No, we actually made our latest surface-emitting diode lasers smaller than the head of a pin. But what's really incredible are the opportunities they've opened for miniaturizing equipment in medicine, computing and satellite communications.

**1987**
During the early 60's, we were a pioneer in superconductivity research, and the leader in developing commercial applications for superconducting wire which operated at extremely low temperatures. Modern superconductors have no resistance to electricity at twice the previous temperature and can levitate a magnet like the one shown here, but we're working on superconductive circuits that will operate at room temperature.

**1982**
Once world communications had been linked via satellite, further innovations seemed highly improbable. Then one of our multidisciplinary research teams developed the first solid state amplifier for use in orbit, which doubled the capacity of our early "birds," and extended their operating life.

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# New Product Ideas

**New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 18). NASA's patent-licensing program to encourage commercial development is described on page 18.**

## High-Capacity Heat-Pipe Evaporator

A heat pipe with a cylindrical heat-input surface has a higher contact thermal conductance than does a comparable one with the usual flat surface. Because the cylindrical heat absorber promotes the nearly uniform flow of heat into the pipe at all places around the periphery of the pipe, it helps to eliminate hotspots on the heat source. (See page 73).

## Reflection-Zone-Plate Antenna

A new type of microwave antenna, based on reflection holography, features a design that can be modified to produce arbitrary beam patterns by controlling the relief pattern. The antenna can be planar or contoured to the supporting structure. The reflective efficiency of this simple device can be doubled by modifying the transmissive rings to phase-shifted reflective rings. (See page 23).

## Adaptive Force and Position Control for Robots

A control system causes the end effector of a robot manipulator to follow a prescribed trajectory and apply the desired force or torque to an object that it is manipulating. The system does not require knowledge of the complicated model of the dynamics of the manipulator and its environment. (See page 41).

## Flexible, Polymer-Filled Metallic Conductors

A procedure has been developed to make materials that are both flexible and reasonably good electrical conductors. Beneficial properties of such a material were demonstrated by a mixture of 76 volume percent gold and 24 volume percent polytetrafluoroethylene codeposited by ion-beam sputtering on a polyimide substrate. (See page 57).

**This symbol** appears next to technical briefs which describe inventions having potential commercial applications as new products. The process for developing a product from a NASA invention is described at the top of this page.

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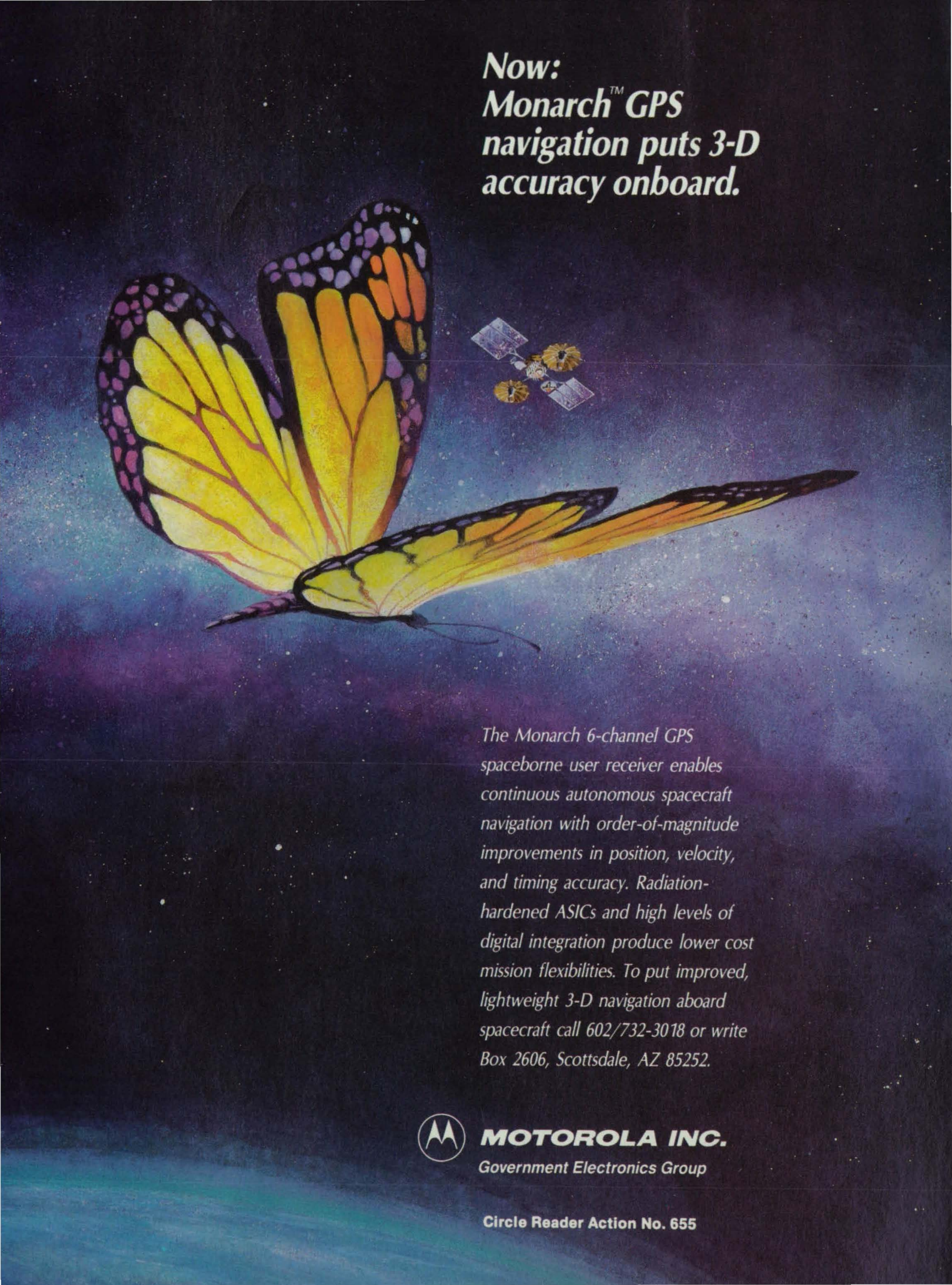
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## Bipolar Battery Using Conductive-Fiber Composite

Improved lead/acid battery features reduced weight and increased energy and power densities.


*NASA's Jet Propulsion Laboratory, Pasadena, California*


In an improved version of the bipolar lead/sulfuric acid battery, electrically-conducting fiber/polymer composite substrates are used in place of metallic substrates. Sealing and corrosion problems associated with metallic substrates are thereby reduced. Other benefits include a halving of weight, increased energy and power densities, and a much lower gassing rate.

A conventional bipolar battery includes electrodes on which positive active material ($PbO_2$) forms one surface and negative active material (Pb) forms the opposite surface. Sandwiched between the two surfaces is a substrate, usually a metal, that conducts electrons but not electrolyte ions. Bipolar electrodes are stacked into a multicell battery such that the electrolyte and separators lie between adjacent electrodes. The end electrodes are unipolar, of course.

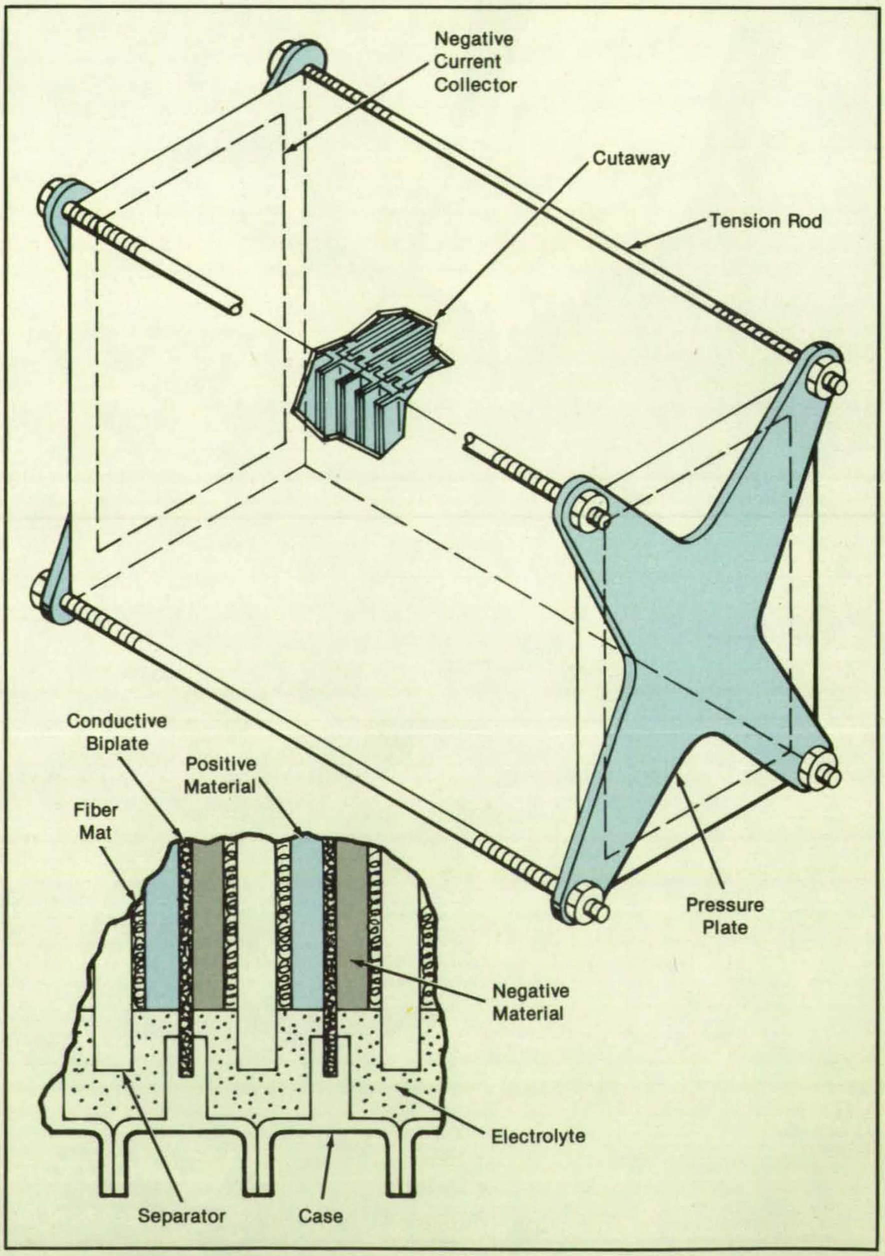
In the improved bipolar battery (see figure), the conductive biplates and bipolar separators are made from a composite — typically, 50 percent by weight of graphite fibers embedded in polyethylene. Electrical contact between the biplate and the active material is achieved by narrow lead stripes plated onto the biplate surfaces.

Each bipolar separator is composed of a sheet of the composite, on each side of which is bonded a porous graded glass-fiber mat. The glass mats hold the positive and negative electrode materials in place. They provide transverse porosity for $H_2$ and $O_2$ gases and add to the axial compliance of the bipolar stack, thus assuring uniform clamping pressure. The positive-side mat also protects the separator from oxidation by contact with the $PbO_2$.

As shown, the entire assembly is clamped between pressure plates. The axial pressure helps to contain active material and to maintain electrical contact between the active material and the biplates.

The amount of $H_2$ and $O_2$ gases given off depends on the amount of antimony in the grid structure. Antimony is normally added to give structural strength and to improve adhesion of the $PbO_2$ to the grid. The improved battery uses no antimony and no grid, with the result that gas is evolved at about one-tenth of the usual rate. Thus, electrolyte needs to be added at about a tenth of the usual frequency, and safety is increased because of the reduction in hydrogen gas.

Sealing problems are largely eliminated




A **Bipolar Lead/Acid Battery** using the new composite materials contains unit cells clamped together between pressure plates. Among other benefits conferred by the new approach, the clamping pressure improves the retention of the electrode materials.

since, unlike metals, the fiber composite is easily bonded to the non-conductive plastics used to construct the battery case. Improved energy and power densities are due, in part, to the elimination of the grid masses and grid losses and to the use of reduced active-material thickness and improved surface-to-volume ratios.

The improved bipolar battery can be used in all customary storage-battery applications. Because of its improved energy-to-weight ratio, it should be especially important for electric-vehicle development.

*This work was done by Wally E. Rippel of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 65 on the TSP Request Card.*

*Title to this invention, covered by U.S. Patent No. 4,353,969, has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)]. Inquiries concerning licenses for its commercial development should be addressed to*

*Edward Ansell*
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*1207 East California Boulevard*
*Pasadena, CA 91125*

*Refer to NPO-14994, volume and number of this* NASA Tech Briefs *issue, and the page number.*

## Photodiode-Coupled Light Modulator

The absorption of one light beam would control the transmission of another.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed high-performance monolithic light modulator would comprise a p-doped/intrinsic/n-doped (PIN) GaAs photodiode grown directly over an InAs/GaAs PIN multiple-quantum-well (MQW) diode (see figure). The construction of the new modulator depends on recent advances in molecular-beam epitaxy, which make possible the growth of such new types of InAs/GaAs strain-layer semiconductor microstructures as MQW's and compositional superlattices that have enhanced electro-optical properties. Standard lithographic and etching techniques could be used to form two-dimensional arrays of the modulator elements for use as spatial light modulators. These would be useful in the processing of images or other arrays of data at very high throughput rates. Metal/semiconductor field-effect-transistor circuitry could be included on the periphery of the GaAs chip for control of voltage and frequency to the array.

In the new modulator, the "writing" (modulating) signal would be a beam of light of photon energy greater than the GaAs bandgap, while the "reading" signal (the signal to be modulated) would be a light beam of photon energy less than the bandgap and at the exciton level of the MQW's. The "writing" signal would be absorbed in the upper diode: this would charge the $n^+/p^+$ node with the integrated photocurrent and thus increase the voltage across the MQW diode. This increase in voltage increases the electric field. Acting on the MQW's and via the quantum confined Stark effect, modulates the transmission of the reading signal through the MQW diode. The information written in the modulator is erased when the applied voltage V is set to zero. Therefore, the integration time (or sensitivity) and frequency response can be selected for a given application.

Since this modulator is transparent to the reading signal, it is practical to transmit the reading signal through the GaAs substrate without having to make membrane structures (by etching the substrate), as is done in the case of AlGaAs/GaAs MQW's. The use of the InAs/GaAs for the MQW's offers the flexibility of tailoring the quantum

level and, hence, the wavelength of the reading beam to the longer wavelengths associated with fiber optics; e.g., 1.3 or 1.55 $\mu$m. Its use in conjunction with <111> oriented substrates offers potential of enhanced electro-optic effects due to strain.

*This work was done by Joseph Maserjian and Sverre T. Eng of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 104 on the TSP Request Card.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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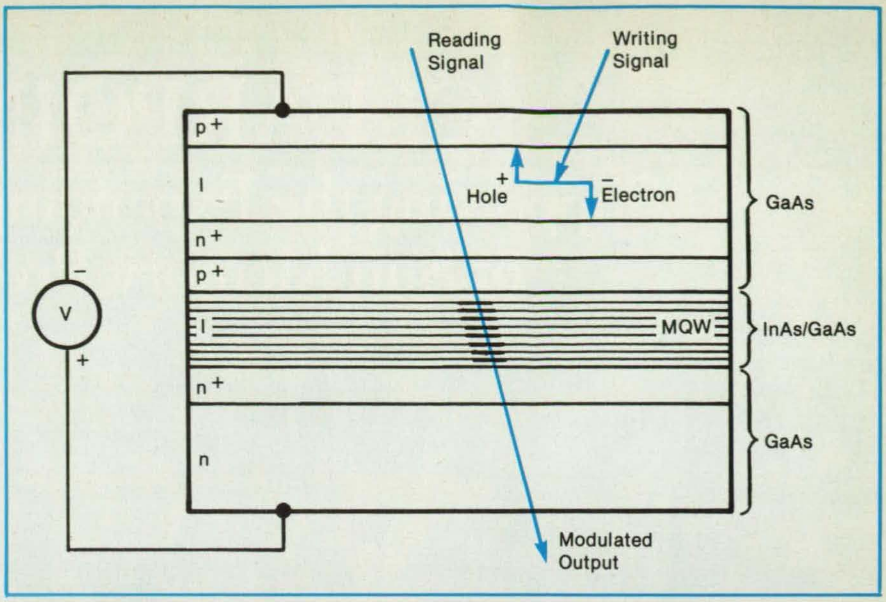


A **Photodiode-Coupled Multiple-Quantum-Well Modulator** would include advanced semiconductor microstructures that have enhanced electro-optical properties. Using standard lithographic and etching techniques for defining picture elements, such structures could be fabricated into two-dimensional arrays for use as spatial light modulators.

## Reflection-Zone-Plate Antenna

A microwave antenna is based on reflection holography.

*Langley Research Center, Hampton, Virginia*

A new type of microwave antenna, based on reflection holography, has been designed and tested. The design can be modified to produce arbitrary beam patterns by controlling the relief pattern, and the antenna can be planar or contoured to the supporting structure. The antenna has a low off-axis radar cross section at frequencies removed from the operational frequency.

Many large-aperture microwave antennas are adaptations of optical systems, the most common being parabolic reflectors

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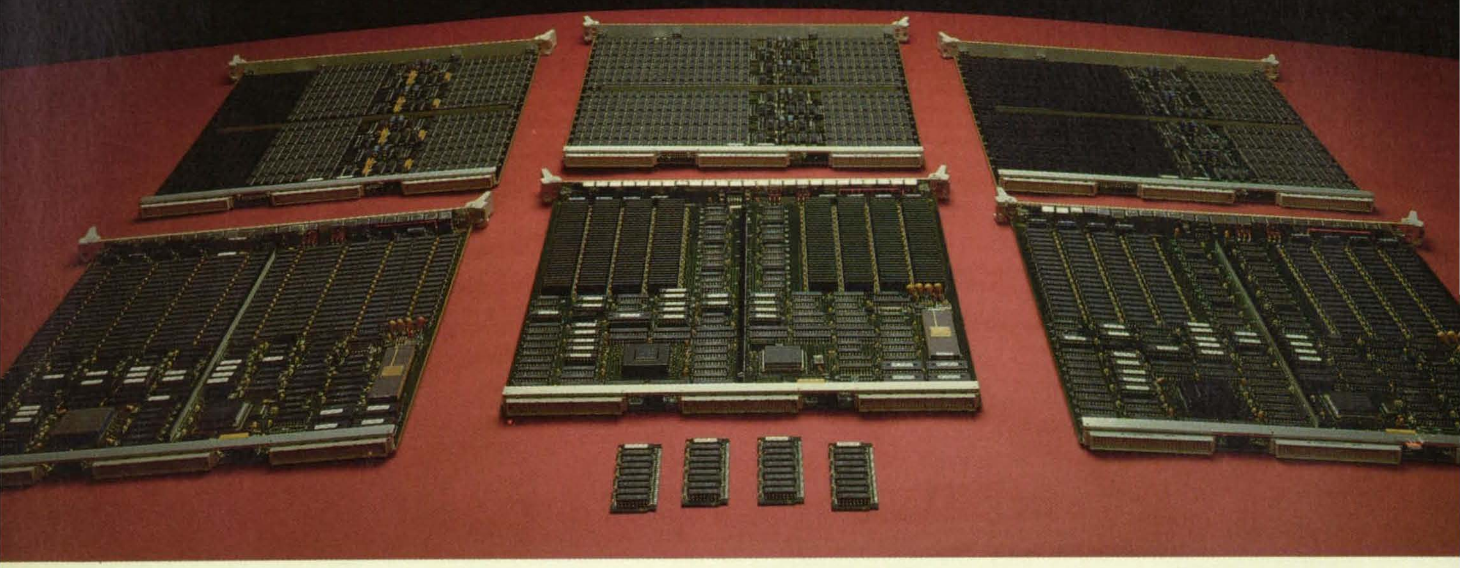

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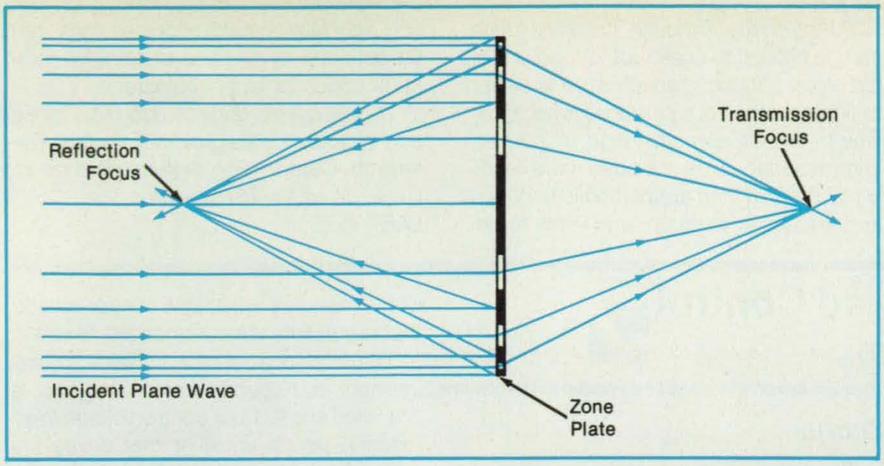



Figure 1. The **Reflective Efficiency** of this simple device can be doubled by modifying the transmissive rings to phase-shifted reflective rings.

used for satellite reception. However, the state of the art in the design of optical elements now extends to holography. The interference pattern produced by a spherical wave intersecting a plane wave consists of concentric circles similar to Newton's rings. This pattern is identical to that of a Fresnel zone plate, which has lens properties. A plane wave incident on such a hologram, or zone plate, is focused to a point.

Figure 1 shows an edge-on sectional view of a zone plate that consists of alternating transparent and opaque concentric circles. If the opaque circles are made from a highly reflective metal, the transmitted energy of the incident plane wave is focused to a point to the right of the plate, and the equivalent reflected energy is focused to a point to the left.

The efficiency of this device as a reflection-zone plate can be doubled by modifying the transmissive areas to introduce a phase reversal to the reflected energy. One way is to place a continuous reflecting plane one-quarter wavelength behind the zone plate. Energy passing through the transmissive circles is reflected back after traveling a total of one-half wavelength, equivalent to a phase change of 180°. Figure 2 shows a 13-zone, phase-reversal antenna 36 in. (0.91m) in diameter mounted in an anechoic test chamber. A single conical horn illuminates the antenna at the design microwave frequency of 11.8 GHz.

The axial chromatic aberration of a zone plate is not a serious problem in micro-

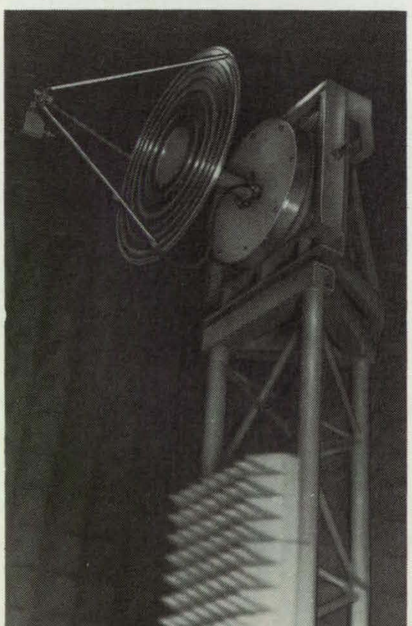


Figure 2. This **Reflection-Zone, Phase-Reversal Antenna** is made by bolting aluminum rings to an aluminum plate.

wave applications, where the signals are typically monochromatic. In fact, chromatic aberration becomes an advantage in that unwanted frequencies are not focused at the feed as they are in parabolic reflectors. This reduces the level of interference and drastically reduces the off-axis radar cross section of the antenna at frequencies removed from the operating frequency.

Furthermore, although the zone plate can be difficult to construct for portions of the electromagnetic spectrum, it is easier to fabricate than is a parabolic reflector or lens in the wavelength range of interest. The flat surfaces are obviously more readily machinable than are parabolic surfaces and are easier to mount and verify for installed-surface accuracy. Finally, off-axis and specially-shaped beam designs can be obtained by the use of existing computer codes for binary holograms.

*This work was done by John M. Franke and Bradley D. Leighty of* **Langley Research Center**. *For further information, Circle 54 on the TSP Request Card.*
*LAR-13537*

# Closed-Loop Motor-Speed Control

Speed is sensed optoelectronically.

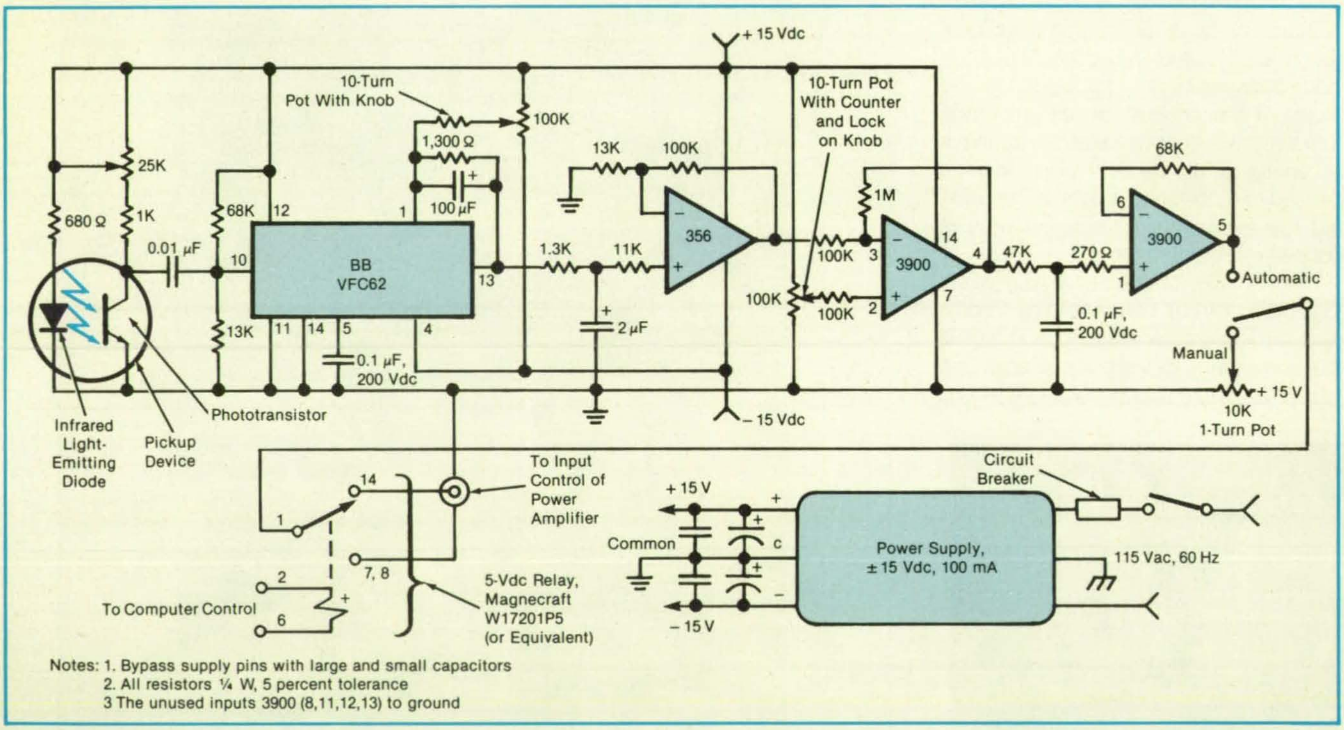
*Marshall Space Flight Center, Alabama*

The electronic motor-speed control circuit shown in the figure is designed to operate in an electrically noisy environment. The circuit includes an optoelectronic pickup device, which is placed inside the motor housing to provide a speed feedback signal. The circuit automatically maintains the speed of the motor at a commanded value. The major advantage of the particular circuit design is low cost.

The pickup device contains an infrared light-emitting diode and a phototransistor. The radiation from the diode is chopped by the fan blades of the motor into pulses, which are detected by the phototransistor. The train of pulses from the phototransistor is fed to a frequency-to-voltage converter, the output of which is a voltage proportional to the speed of the motor. This voltage is low-pass filtered, amplified, and compared with a manually-adjustable control voltage that represents the commanded speed.

The difference between the speed-measurement and speed-command signals is amplified and fed as a control voltage to an external power amplifier that drives the motor. A selector switch at the output of the final amplifier of this circuit also enables the operator to bypass the circuit and manually set the control voltage for the external amplifier.

*This work was done by Matthew A. Smith, Ray C. Delcher, and Steven W. Huston of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.* *MFS-29469*




The **Speed-Control Circuit** measures the speed of the motor in terms of the frequency of pulses of infrared light chopped by the fan blades of the motor. The difference between the measured and commanded speeds serves as a control signal for an external amplifier that drives the motor.

# Measuring Fracture Times of Ceramics

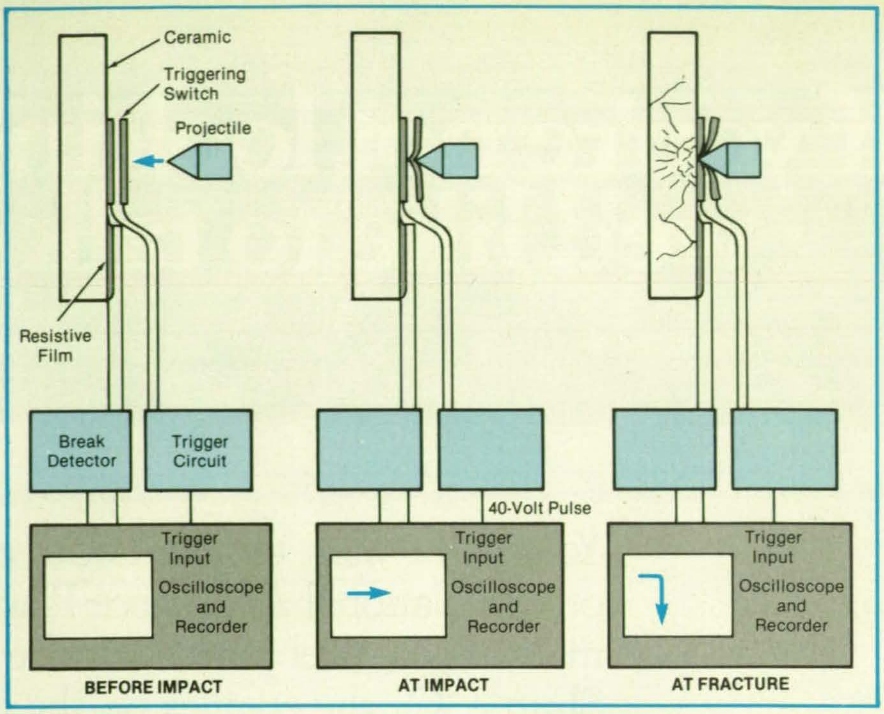
Electrical measurements complement or replace fast cinematography.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A relatively simple electronic system measures the microsecond time intervals between the impacts of projectiles on ceramic tiles and the fracture of the tiles. The instrumentation is used in research on ceramics and ceramic-based composite materials such as armor. The hardness and low density of ceramics enable them to disintegrate projectiles more efficiently than metals can. However, the ceramics also disintegrate in the process, and research on ceramic armor depends on

the accurate measurements of the intervals between impacts and disintegrations to ensure that the energies of the projectiles can be fully dissipated. High-speed cameras have been used to measure the intervals, but they are not precise or fast enough in the microsecond range.

The instrumentation includes a patterned resistive film on the ceramic specimen, a triggering switch, break-detection circuitry, and an oscilloscope (see figure). The triggering device detects the projectile at the instant of impact and signals the oscilloscope to start measuring time. As cracks propagate through the ceramic, they cut through the resistive film, increasing its resistance. The break-detection circuit senses the increase and increases the voltage to the oscilloscope proportionately. The oscilloscope thus generates a plot of the increasing resistance between impact and final disintegration during an interval of a few microseconds. The trace data are recorded on magnetic diskettes and on photographs of the oscilloscope traces.




A **Projectile Approaches** a ceramic tile specimen (left). Penetrating the foil squares of a triggering device, it activates the display and recording instruments (center). As the ceramic and resistive film break, the oscilloscope plots the increase in the electrical resistance of the film (right).

The resistive film is formed by photolithography. First, an insulating layer of amorphous silicon 3,000 Å thick is deposited on the surface of the ceramic specimen. A layer of aluminum or titanium, also 3,000 Å thick, is deposited on the silicon by evaporation. A layer of photoresist is applied to the metal film and exposed to a pattern of concentric convoluted lines. The pattern is etched into the photoresist and into the metal film below it, leaving concentric convoluted arcs of metal on the ceramic. As the ceramic breaks after impact, the lines are cut progressively.

Eight break-detection circuits monitor the integrity of segments of the metal lines. Each circuit generates a negative 5.6-V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| 44 | 0.15 | 0.75 | 1.20 |
| 60 | 0.20 | 1.25 | 2.00 |

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signal for the oscilloscope when its associated segment is broken.

The triggering switch consists of two squares of copper foil separated by an air-gap of 0.02 in. (0.5 mm). One square is bonded to the face of the specimen. When the projectile strikes the other square, it closes the gap, sending a 40-V pulse to the instrumentation to start the measurement of time.

*This work was done by Paul J. Shlichta, Leo Bister, and Donald G. Bickler of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 143 on the TSP Request Card. NPO-16738*

# Jacobi-Bessel Analysis of Antennas with Elliptical Apertures

A coordinate transformation improves convergence in pattern analysis of elliptical-aperture antennas.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A modified version of the Jacobi-Bessel expansion for the vector diffraction analysis of reflector antennas uses a coordinate transformation to improve convergence with elliptical apertures. The usual Jacobi-Bessel expansion converges rapidly (i.e., requires relatively few terms) for antennas with circular apertures, but less rapidly for elliptical apertures.

Because the modified Jacobi polynomials (related to Zernike functions) used are orthogonal functions over circular regions, it is natural to apply them to circular apertures. To apply these functions to an elliptical aperture, the aperture is considered to be circumscribed by a circle of diameter equal to the major elliptical axis, and the induced current on the portion of the reflector surface between the circle and the ellipse is assumed to be zero. Because of this discontinuity in the integrand, more terms of the series than would otherwise be needed must be computed to achieve adequate convergence.

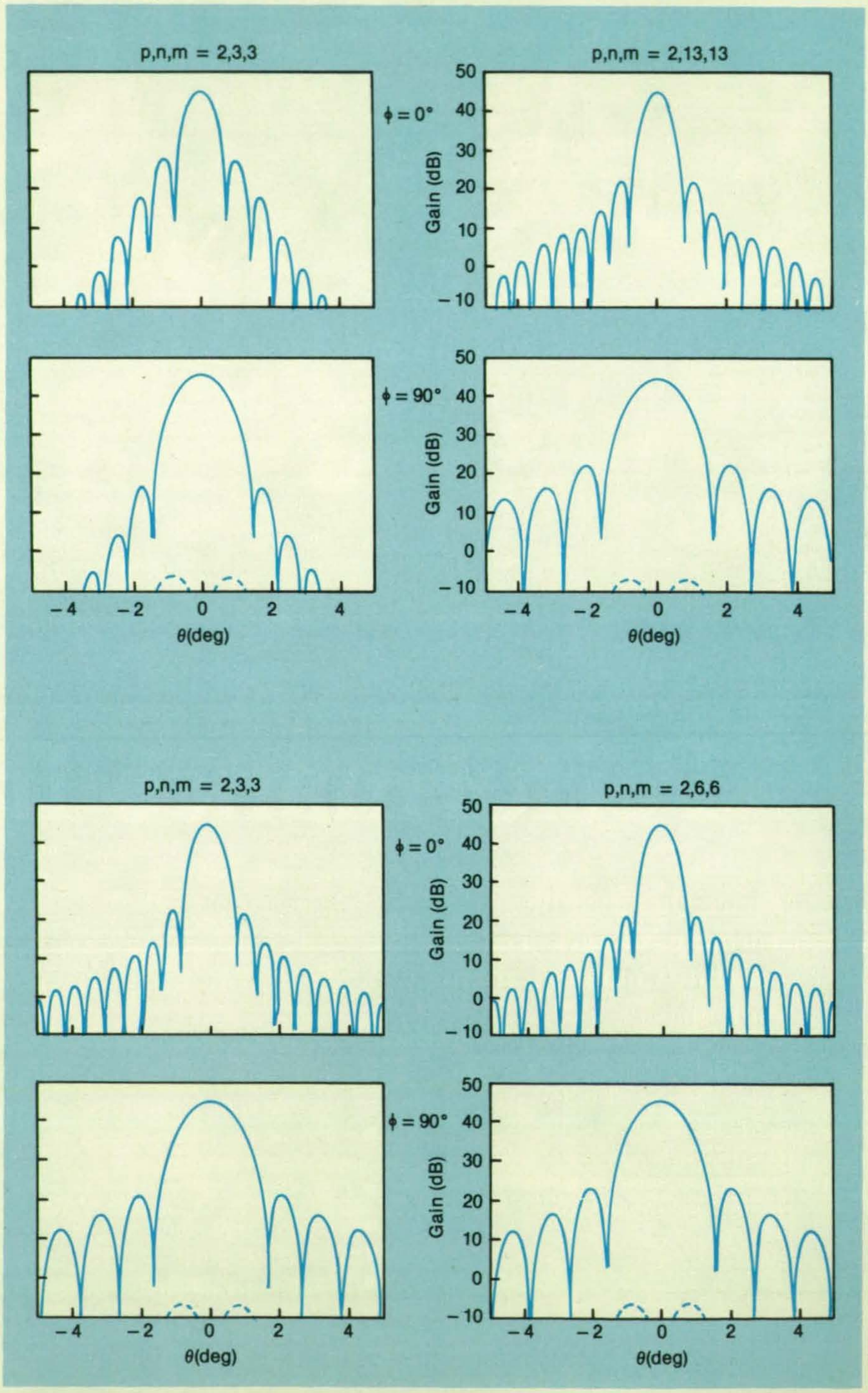
The lack of convergence can be remedied by the use of a coordinate transformation that re-expresses the elliptical case in a form that is circular in the new variable space. The radiation integral can be tailored for an elliptical projected aperture with major and minor axes of 2a and 2b by the following change of variables in the integrand

$$x' = at \cos \Psi$$
$$y' = bt \sin \Psi, \text{ and}$$
$$dx'\,dy' = abt\,dt\,d\Psi$$

where $x'$ and $y'$ are the original orthogonal coordinates in the aperture plane and $\Psi$ is the azimuthal angle in the transformed aperture plane.

After applying this transformation, performing a Taylor-series expansion with a central plane chosen to be as close to the reflector rim as possible, incorporating the Jacobi-Bessel expansion, and some additional manipulations, the resulting expansion converges much more rapidly than does the original expansion (see figure). It is a simple matter to modify existing circular Jacobi-Bessel computer programs to incorporate the elliptical algorithm.

*This work was done by Y. Rahmat-Samii of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 32 on the TSP Request Card. NPO-16967*




The **Difference in Convergence Behavior** between the circular Jacobi-Bessel (top) and the elliptical Jacobi-Bessel (bottom) algorithms is indicated by the highest values of the indices m, n, and p (indicative of the order of the expansion) required to achieve the same accuracy in the computed radiation pattern of an offset paraboloidal antenna with an elliptical aperture.

# Optoelectronic Technique Eliminates Common-Mode Voltages

Small signals can be transmitted between circuits at large differences of potential.

*Lewis Research Center, Cleveland, Ohio*

An optoelectronic technique lends itself well to the accurate measurement of any electrical parameter and the display of its value. The technique can accommodate a broad range of measured values from millivolts to hundreds of volts and can provide unlimited electrical isolation. In this technique, the measured parameter is converted to the duration, proportional to its value, of a pulse of light. The pulse is transmitted along an optical fiber to or from the isolated circuit.

At the transmitter, the measured parameter is converted to the durations of pulses in a common digital panel meter. It is necessary only to locate the point in the meter circuit where there is a correspondence between the measured parameter and the durations of pulses. This point is not normally used to obtain output from the meter. The signal at this point is suitably conditioned by added transistors to drive the transmitter at one end of the optical fiber.

Power to operate the additional components is supplied by the meter. The components of the optical link include low-cost, snap-in, transmitter/receiver pairs connected with 1-mm-diameter plastic-fiber cable. These devices are relatively new, very rugged, able to operate from dc to 5 MBd, and require little electrical current.

At the receiver, the pulse of light in the fiber is converted back into an electrical pulse, the duration of which is measured by counting the number of clock pulses accumulated in a 12-bit binary counter during the pulse time. On the falling edge of the pulse, the count is strobed into a 12-bit digital-to-analog converter to provide an analog output of 0 to 10 volts proportional to the count. The scale of the digital and analog values is easily changed by changing the clock frequency: The analog output is proportional to the clock frequency.

This technique could be used wherever it is desired to measure, record, and/or control parameters of circuits that are floating at high voltages. It could also be used to prevent ground loops in low-voltage applications. In addition, two circuits, one in each direction, could be used in a control-loop configuration.

Some specific applications could be in the operation of traveling-wave tubes (TWT's) or other electron-gun devices that include filaments at cathode potential. This potential, generally about 10 kV, prevents the direct recording of filament voltage (6 V) or filament current (0.2 to 5 A). Another TWT application is the measurement of control-grid voltage, which controls the beam current and which is established with respect to the cathode.

The technique can be used for the optimization and testing of depressed-collector/microwave-tube combinations. Yet another possible application is in the measurement of current from, or the control of, series stacked power supplies.

*This work was done by Gary G. Lesny of* **Lewis Research Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14529.*

## Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

### Advanced Components for Fiber-Optical Systems

This concise review emphasizes highly birefringent fibers, couplers, and polarizers.

A paper reviews the statuses of some advanced passive and active optical components for use with optical fibers. The emphasis is on highly birefringent components that control polarization, because the control of polarization is critical in such applications as fiber-optical gyroscopes, interferometric sensors, and coherent communications.

The classes of passive components reviewed include highly birefringent fibers, coupler-based devices, and polarizers. Birefringent fibers have elliptical, stressed, cut, or otherwise non-circularly-symmetrical cores that maintain polarization. Such fibers are expensive (>$10/m) but perform well in that cross-coupling to the undesired polarization is typically less than $5 \times 10^{-3}$ $(km)^{-1}$.

The coupler-based components include polished and fused single-mode couplers, special items that perform at several wavelengths, arrays of high uniformity, and units made partly of highly birefringent fibers. Some of these devices couple both polarizations to the same degree, while others have been built to couple primarily one polarization, thus acting analogously to polarizing beam splitters.

Fiber polarizers are made by a polishing technique similar to that used to make some couplers. In this approach, a dielectric layer and then a metal layer are deposited on the polished face of a flat longitudinal cut that passes near the axis at a bend in the fiber. In an alternative version, only a metallic layer is deposited.

The active components of interest include piezoelectric transducers that indirectly produce optoelectronic or electro-optical effects to modulate phase, frequency, or polarization. Typically, a piezoelectric device surrounds a fiber and constricts it when an electrical signal is applied. The constriction gives rise to the birefringence that modulates the light traveling along the fiber.

*This work was done by Ramon De Paula of Caltech and David W. Stowe of Aster Corp. for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Overview of Advanced Components for Fiber Optic Systems," Circle 53 on the TSP Request Card.* NPO-17080

# Multiple-Beam Communications Antenna

This system has both fixed-spot and scanning coverage.

*Lewis Research Center, Cleveland, Ohio*

Advanced offset-fed spacecraft antenna systems operating in the 30/20 GHz frequency bands have been developed that can provide multiple-radiating fixed-spot and regional-coverage scanning beams for use on communications satellites. These antennas, operating at the higher frequencies, will provide alternate frequency bands for expansion of existing satellite services as well as achieving frequency reuse capability for conservation of the frequency spectrum.

The satellite antenna configuration uses separate uplink and downlink antennas. Each antenna provides narrow fixed-spot beams to major cities of the continental United States (CONUS) and scanning beams that cover wide-angle geographic areas (sectors) of the CONUS. The spot beams provide the communications coverage for high-volume traffic between major cities, where each beam will cover an area approximately 200 m (322 km) in diameter, and the spacing of the spots across the country allows reuse of the same frequency in many beams. The scanning beams provide coverage for direct-to-user services to remotely located areas according to the demands of the users.

The primary function of the multiple-beam antenna system is to receive the message traffic from the major trunk-beam cities and scanning areas, route this information through an onboard switch or message-processing system, and then transmit these messages to their respective destinations.

The antenna system will provide 18 trunking beams to preassigned major cities of the CONUS and 6 scanning beams, each covering approximately one-sixth of the CONUS. The separate receiving and transmitting antennas are operationally similar except for frequency scaling of dimensions. Each antenna beam has a beam width of 0.3° and a gain of 50 to 53 dB or more. They will provide isolation of 30 dB between individual spots. The control system for the scanning beams allows any one uplink or downlink beam to be independently sequenced to any one of its positions. The dwell time at each position is programmable between 10 and 100 $\mu$s, and the switching time between beam positions is less than 0.5 s.

Both the 20-GHz-transmitting, 30-GHz-receiving antennas use unique concepts in achieving the goals for meeting the requirements for multiple-beam, high-gain, and optimum-beam isolation. The feed network arrays use multiple horns per beam; sharing of horn clusters for trunk and scan beams; orthomode junctions for dual po-

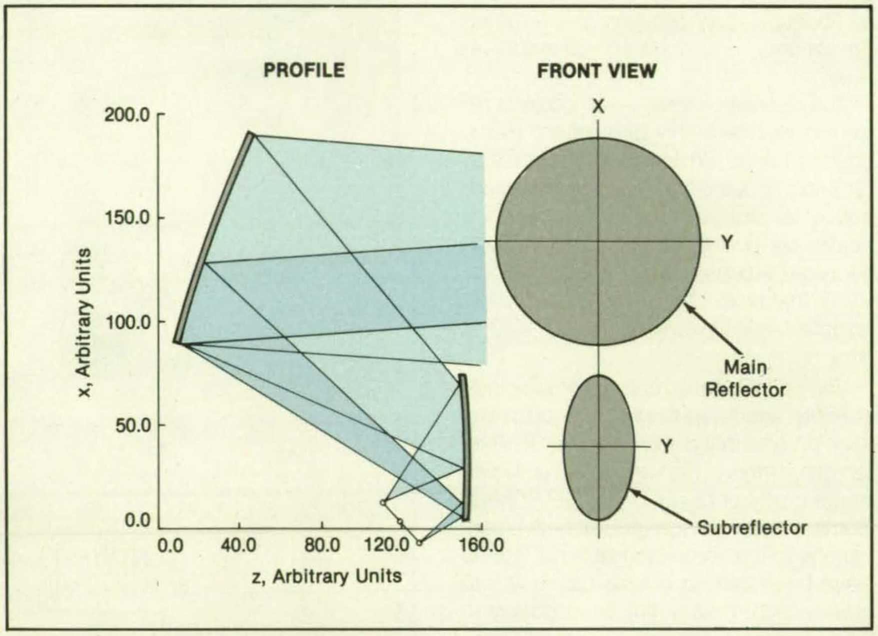



Figure 1. The **20-GHz Transmitting Antenna,** shown schematically here, is an offset-fed, dual-reflector configuration.

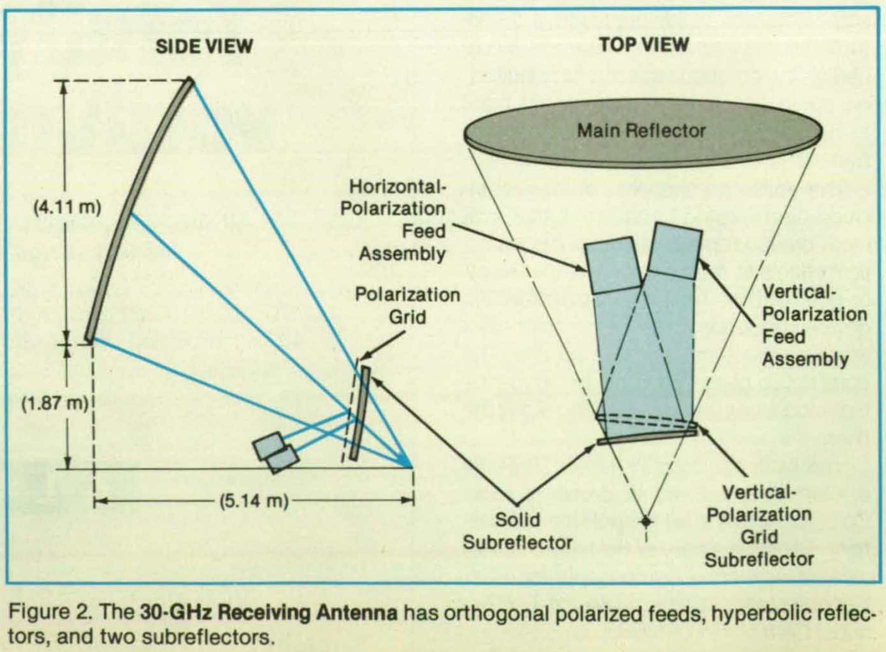



Figure 2. The **30-GHz Receiving Antenna** has orthogonal polarized feeds, hyperbolic reflectors, and two subreflectors.

larization; diplexers for dual frequency use; and high-speed, low-loss ferrite circulator switches, variable power dividers, and variable phase shifters.

The 20-GHz transmitting antenna (see Figure 1) is an offset-fed dual-reflector microwave optical system with planar-array feed consisting of a multiple-port beam-forming-network (BFN). To form the narrow 0.3° beams, the main reflector is 13.5 ft (4.1 m) in diameter, and the subreflector is a nominal 9.5 ft (2.9 m) in diameter. A unique feature of this hardware model is the shaped main and subreflector surfaces to minimize losses over the required field of view. Thus, the reflectors are not portions of a figure of revolution but are each doubly curved surfaces that have no true focal point at the zero-scan beam position, so that defocusing at the edges of the scan field of view is minimized.

The feed assembly BFN lattice uses seven-element, coherently driven horn clusters for each beam. For beam switching, the ferrite circulator switches, variable power dividers, and variable phase shifters have switching energies as low as 40 μJ and weights as low as 12 g. As a result, large numbers of switch components can be used to provide the required multiple beams, the off-axis scan capability, and both vertically and horizontally polarized beams. All results met or exceeded the design goals.

The 30-GHz-receiving-antenna system is of a similar geometry, but uses hyperbolic reflectors, two subreflectors stacked to form a double-layer bifocal subreflector system, and two orthogonally polarized feed assemblies diplexed by a front wire-grid subreflector (Figure 2). To form the narrow receiving-frequency beams, the main reflector is 9.5 ft (2.9 m) in diameter, and the subreflectors are 5.0 ft (1.5 m) in diameter.

The two orthogonally polarized feeds are completely separated into two focal-point-fed areas for higher gains to compensate for the increased scan losses of the off-axis beams. Similarly, the ferrite switching devices scaled to the 30 GHz frequency band used in the receiving feed array have short switching times, low energy input, low losses, and low weight.

The 30- and 20-GHz antenna systems demonstrated that high-frequency, precise-reflector optical systems can be fabricated and that the feed-beam-forming networks can produce very narrow beams for use on geostationary satellites. As a result, advanced communication satellites will expand existing satellite services by means of narrow spot beams and frequency reuse techniques.

*This work was done by R. W. Myhre of* **Lewis Research Center,** *T. E. Roberts of Ford Aerospace & Communications Corp., and W. C. Wong of TRW, Inc. For further information, Circle 122 on the TSP Request Card.* *LEW-14190*

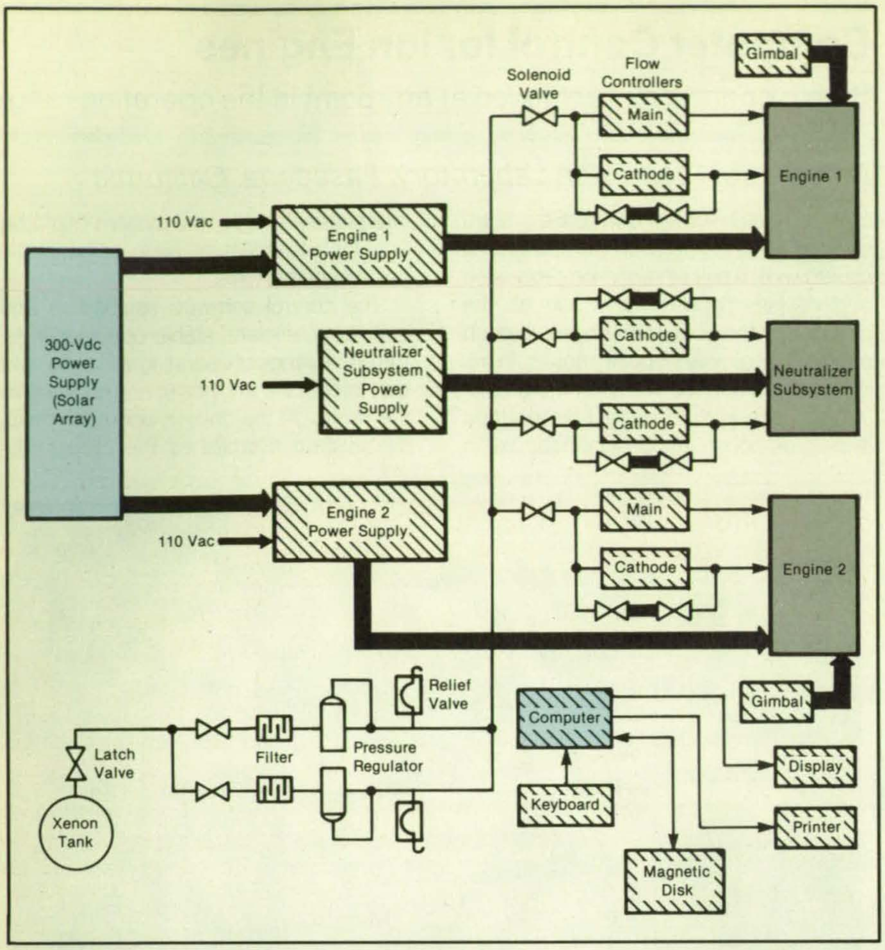
## Computer Control for Ion Engines

Stable operation is achieved at any point in the operating range.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A computer system controls the start-up, steady-state operation, throttling, and shutdown of a pair of xenon-ion propulsion engines (see figure). It also controls the direction of thrust of each engine through operation of gimbal stepping motors. In addition, it controls the valves in the propellant-storage and propellant-distribution system. Although it is designed for use in interplanetary flight, the system might be adaptable to industrial use in ion-beam deposition of thin films.

The control software establishes and maintains efficient, stable operation over the entire range of operating variables, and can throttle the engines to any point within the range. At the chosen operating point, the system establishes the proper dis-



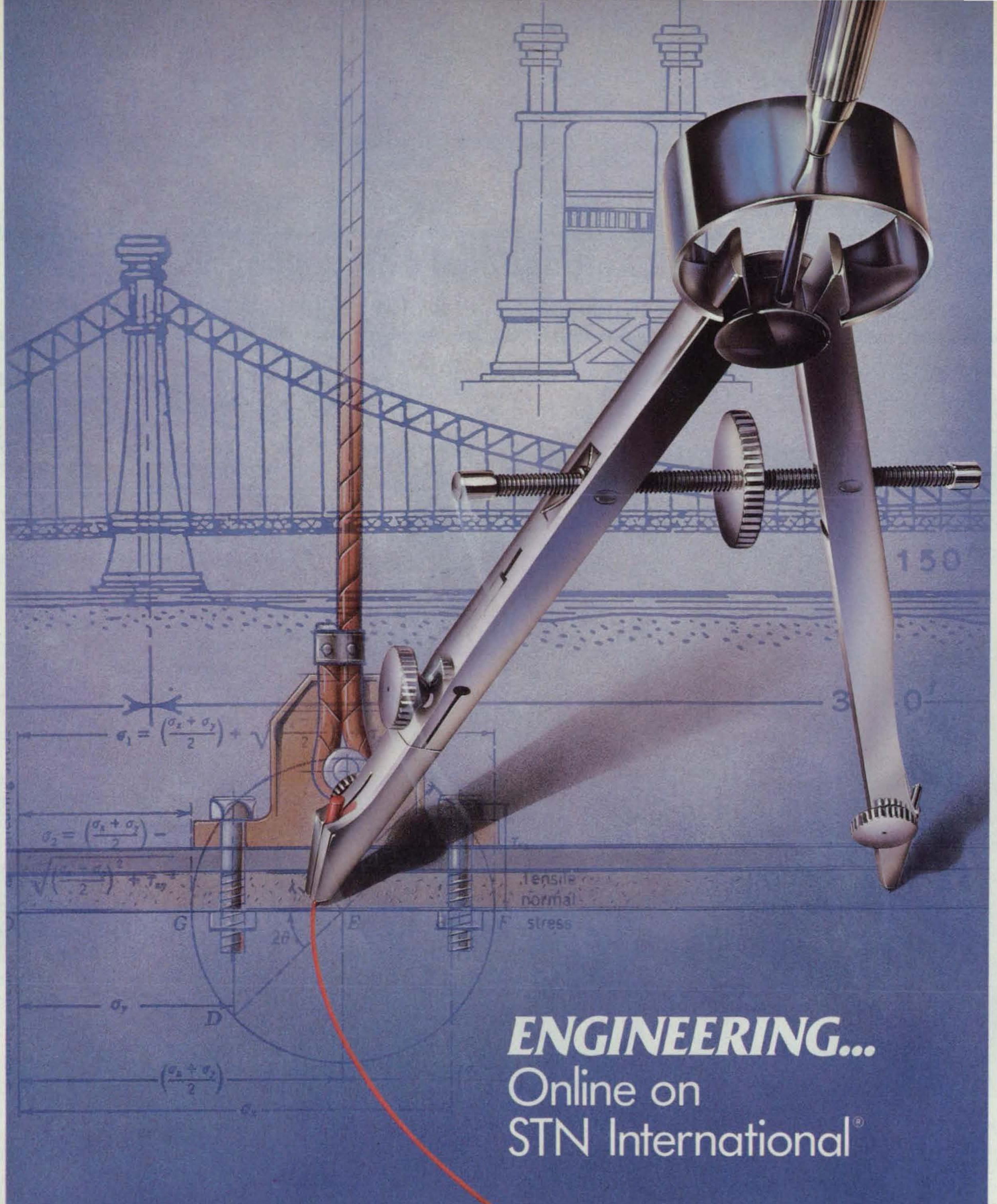

A **Computer Operates the Power Supplies, Valves, and Flow Controllers** of two ion engines, the ion-neutralizer subsystem, and other equipment. Crosshatched areas represent items controlled by the computer.

charge currents and voltages, rates of flow of propellant, and screen voltages. When the operator selects a new operating point, the system changes conditions smoothly so that the engines adjust stably.

Tests show that the control algorithms can operate and throttle the engine stably over a range of beam currents from 1.0 to 4.2 A, corresponding to a variation in input power from 0.7 to 5.5 kW. The control system provides a flexibility in the operation and throttling of ion engines that has not been possible in the past.

Control of the engines is accomplished through proportional control of the discharge current to maintain the desired beam-current set point. Similarly, the cathode flow rate is controlled to maintain the discharge-voltage set point, and the main flow rate is controlled to maintain the desired propellant efficiency. The system may be used to obtain performance curves (plots of discharge loss versus propellant efficiency) at constant discharge voltage since it relentlessly maintains the desired discharge-voltage set point.

The system is based on a personal computer with 20-megabyte hard-disk storage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and 640-kilobyte memory. The computer is linked to commercial mass-flow controllers by two serial data lines via two flow-control and display units. The lines enable the computer to read and to change the xenon flow rates at each of the six flow controllers.

The computer controls the gimbal stepping motors through an interface card in one of its expansion slots. The computer can drive all four stepping motors simultaneously. Through other circuit boards, the computer opens and closes solenoid valves in the propellant system, measures the electrical parameters of the engine and neutralizer, and controls several power supplies. The control program is written in Turbo-Pascal.

*This work was done by John R. Brophy of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 83 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17292.*

# Digital, Satellite-Based Aeronautical Communication

Advanced digital techniques will be needed eventually for greatest cost effectiveness.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed satellite system would relay communication between aircraft and stations on the ground. Such a system would offer better coverage than is now possible with direct communication between the air and the ground, would cost less, and would make possible new communication services.

The system would carry both voice and data. Because many of the data exchanged between an aircraft and the ground contain safety-related information, a low probability of bit errors will be essential.

An aeronautical-mobile/satellite system poses a special combination of conditions for designers. The channels will be subject to a mild form of multipath fading because of the motions of aircraft and satellites. The receivers will be burdened by bursty signals because of the short messages that will be transmitted. Moreover, both the spectrum and the available power will be limited.

An experiment was conducted to examine the characteristics of the aeronautical-mobile/satellite channel (see figure). Delay spreads, scattering coefficients, and other parameters were measured. The experimental data were used to evaluate the merits of wideband versus narrowband transmission and coherent versus noncoherent demodulation.

Given fixed resources of power and spectrum, new digital modulation technologies should be evaluated to bring services to the greatest number of users and thereby reduce costs and increase coverage. For the first-generation system, such proved modulation schemes as quaternary phase-shift keying are good candidates. More advanced techniques like trellis-coded M-ary modulation warrant consideration for later generations, but additional development and experimentation are needed.

Adequate power margin, guard band, and guard time will be needed to ensure reliable operation with semistationary channels. For the sake of safety, data messages will have to be transmitted with error-correcting and error-detecting codes. Voice messages will need little encoding, if any — users can simply request the repetition of unintelligible transmissions.

The proposed information rate per user is 4,800 bits per second. This rate will be

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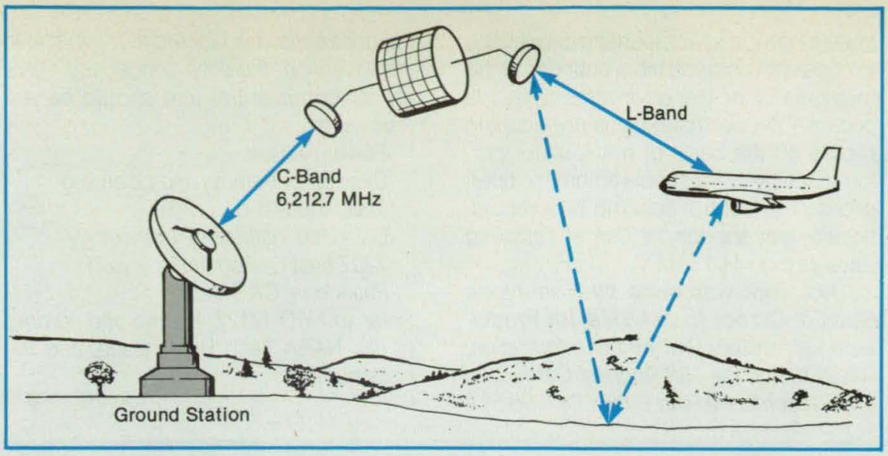



The **Proposed Satellite-Based Communication System** for aircraft was explored in an experiment. The dashed line represents a reflection that contributes to multipath signals—a problem that system designers must take into account.

adequate for data and for speech of fair quality. At 4,800 bits per second, the frequency interval between channels will be 10 kHz or less, depending on the modulation scheme.

*This work was done by F. Davarian of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 129 on the TSP Request Card.* *NPO-17252*

# Adaptive Force and Position Control for Robots

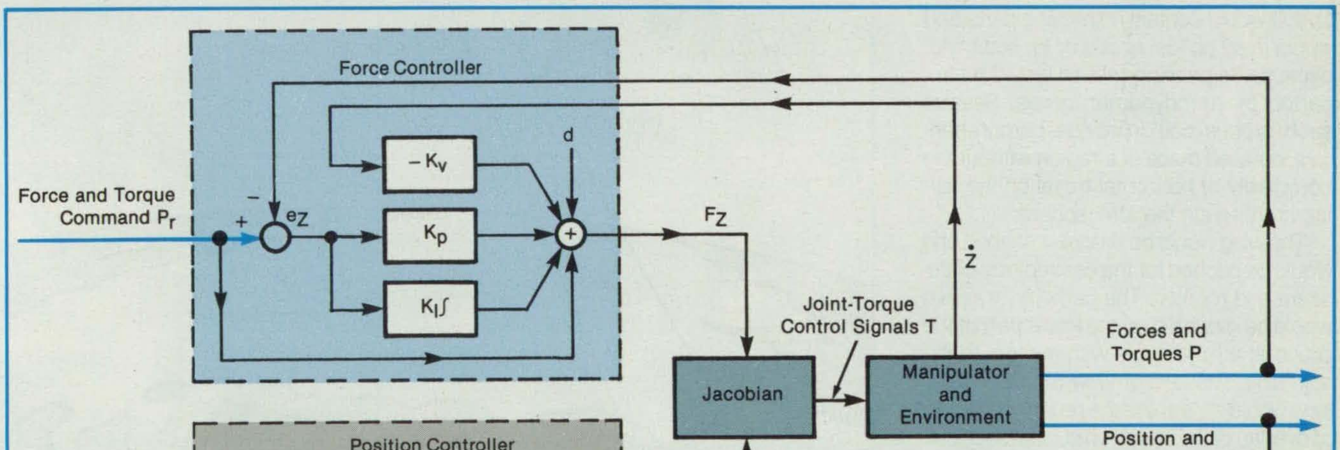
## Precise knowledge of manipulator and environment is not required.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A control system causes the end effector of a robot manipulator to follow a prescribed trajectory and apply the desired force or torque to an object that it is manipulating or with which it is in contact. The system is characterized by a hybrid control architecture, in which the positions and orientations along unconstrained coordinate axes are controlled by a position-control subsystem, while the forces and torques along the constrained coordinate axes are controlled by a force-control subsystem (see figure). The system compensates for the dynamic cross-coupling between the force- and position-control loops and does not require knowledge of the complicated model of the dynamics of the manipulator and its environment.

In the force-control subsystem, the feedforward force vector $P_r$ (representing the desired effector contact forces) is processed along with the measured (feedback) force vector P, an auxiliary signal d, and the velocity feedback $\dot{Z}$ to produce the control vector $F_z$ for the forces and torques applied to the end effector along the constrained axes by the manipulator-joint actuators. The control law includes proportional, integral, and derivative gain matrices $K_p$, $K_I$, and $K_v$, respectively, that vary with time according to the equations of the adaptation scheme, which strives to reduce the error vector, $e_Z$, between the feedforward and feedback force vectors.

The position-control subsystem enforces a linear adaptive control law that produces the manipulator force-and-torque control vector $F_y$ for the unconstrained axes from the feedforward position vector R and from the feedback position and velocity Y and $\dot{Y}$, respectively. An auxiliary vector f and the control-gain matrices K, C, A, B,




The **Control Gains** (represented by the small rectangles on the left) of this position- and force-control system are continually adapted according to prescribed adaptation laws to reduce the error signals $e_Y$ and $e_Z$.

and $K_d$ are calculated according to adaptation equations, the forms of which resemble those of the force controller, and which reduce the error vector $e_Y$.

The force- and position-control signals are in Cartesian coordinates of the workspace and are transformed to equivalent joint-torque-control signals in manipulator-joint space via the Jacobian matrix of the manipulator-joint coordinate system. The dynamic cross-coupling effects are mathematically modeled as disturbance terms in the force- and position-control loops.

The adaptive force and position controllers have, in effect, learning capabilities to cope with unpredictable changes in the manipulator or the environment; this is because the controller gains are adapted rapidly on the basis of manipulator performance by use of simple arithmetic operations. The control scheme is computationally fast enough for use at sampling rates as high as 1 kHz.

*This work was done by Homayoun Seraji of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 139 on the TSP Request Card.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*Edward Ansell,*
*Director of Patents and Licensing*
*Mail Stop 301-6*
*California Institute of Technology*
*1207 East California Boulevard*
*Pasadena, CA 91125*

*Refer to NPO-17127, volume and number of this* NASA Tech Briefs *issue, and the page number.*

# Samara Probe for Remote Imaging

This conceptual device would scan automatically, without costly aiming or stabilizing devices.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

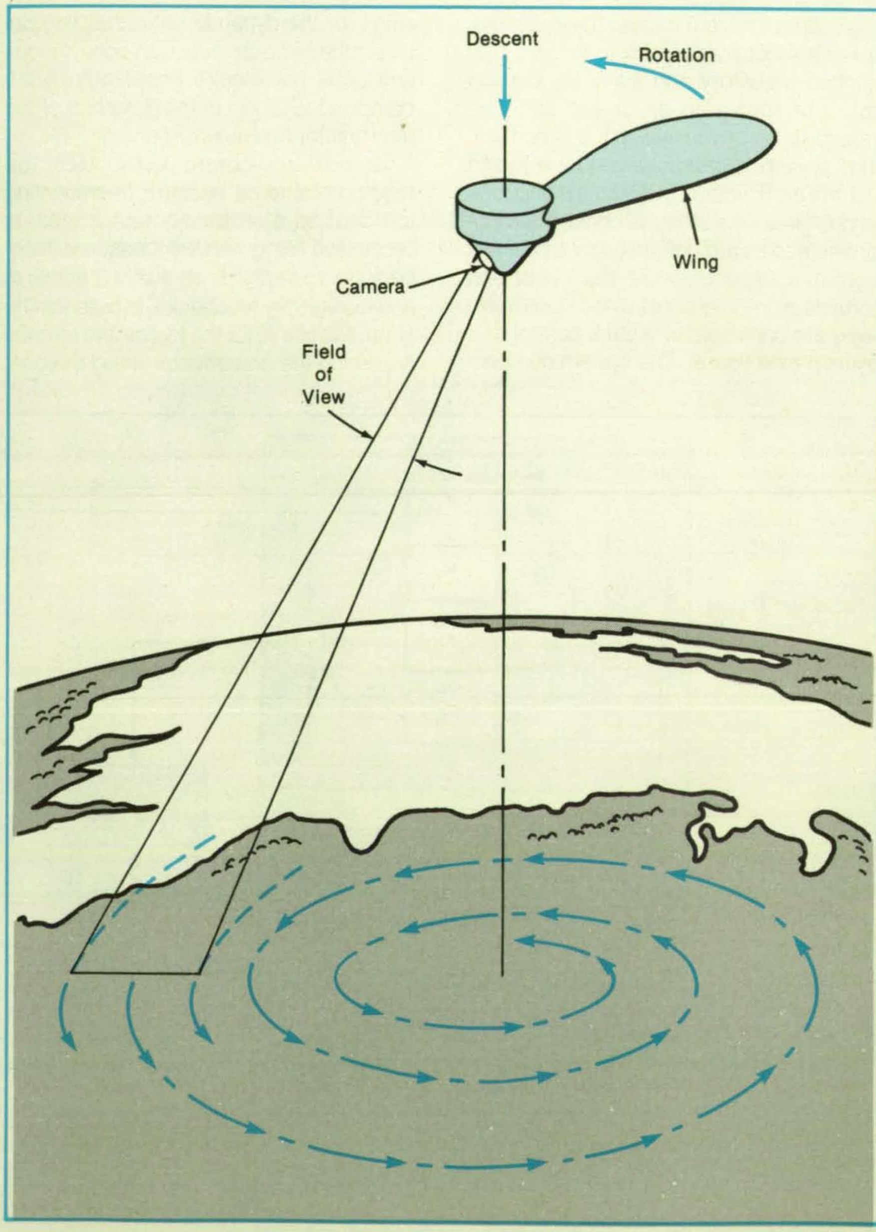
A proposed imaging probe would descend through the atmosphere of a planet, obtaining images of the ground surface as it travels. The probe could be released from an aircraft over the Earth or from a spacecraft over another planet.

The probe would have a body and a single wing shaped much like a samara — a winged seed like those of maple trees. It would therefore rotate as it descends, providing a panoramic view of the terrain below (see figure). The probe would radio the image obtained by its video camera to the aircraft or spacecraft overhead.

The probe would be simple and inexpensive. It would contain no moving parts and would need no fuel or power for scanning, because its panning motion would be imparted by aerodynamic forces. Several such probes could provide comprehensive, detailed maps of a region without the complexity of horizontal travel on the surface or through the atmosphere.

The wing would be propeller shaped and would be pitched for the desired rate of descent and rotation. The camera (or radar) would be mounted on the lower part of the probe at a fixed angle with respect to the spin axis. The field of view of the camera lens would determine the required amount of overlap of the image on successive rotations; a wider angle would cause more — and earlier — overlap. The resolution of the image would increase gradually as the probe approaches the surface.

The upper surface of the wing could carry solar-cell panels, if necessary, to supply power to the camera and transmitter. The transmitting antenna would be embedded in the probe. The wing could also carry a Sun sensor to furnish data on orientation and spin to aid in subsequent processing of the images. (Image processing would be required to remove effects due to nutation and wind drift.) A second wing, like that on certain seeds, could be added to slow the descent and reduce nutation.




The **Autorotating Probe Would Give Images** of areas along a spiral path. The probes should be inexpensive enough that many such units could be deployed to cover a large area.


USA
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DESTINED FOR BIGGER THINGS.
America's space program is again under way. But we've already lost precious time. Other countries and companies, even American ones, have been looking to alternative vehicles to get their space projects aloft. In terms of old-fashioned business sense, NASA is facing stiff competition.
The Shuttle's work is cut out for it. NASA's plan to recapture American preeminence in the space delivery business is to amplify the payload capacity of the Shuttle. Their goal is a 17% increase in Shuttle utilization. With huge programs like the Space Station Freedom in the wings, this harder-working delivery vehicle is vital.
The team of Lockheed Missiles & Space Company and Aerojet, a subsidiary of GenCorp, has the solution: a new, more powerful Advanced Solid Rocket Motor. The Lockheed and Aerojet team proposal is a motor that will be manufactured by a "continuous mix" process, resulting in not only more thrust, but with a more controlled burn. The payoff will be a Shuttle that is both more muscular and more reliable.
America's destiny in space has a glorious future; but to get there takes the right mix: Lockheed and Aerojet.
Lockheed & Aerojet
Because it must work every time.
Circle Reader Action No. 490
Photo courtesy of NASA

*This work was done by James D. Burke of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 124 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18] Refer to NPO-17390.*

# Video Alignment System for Remote Manipulator

## Crosshairs and a mirror provide angular references.

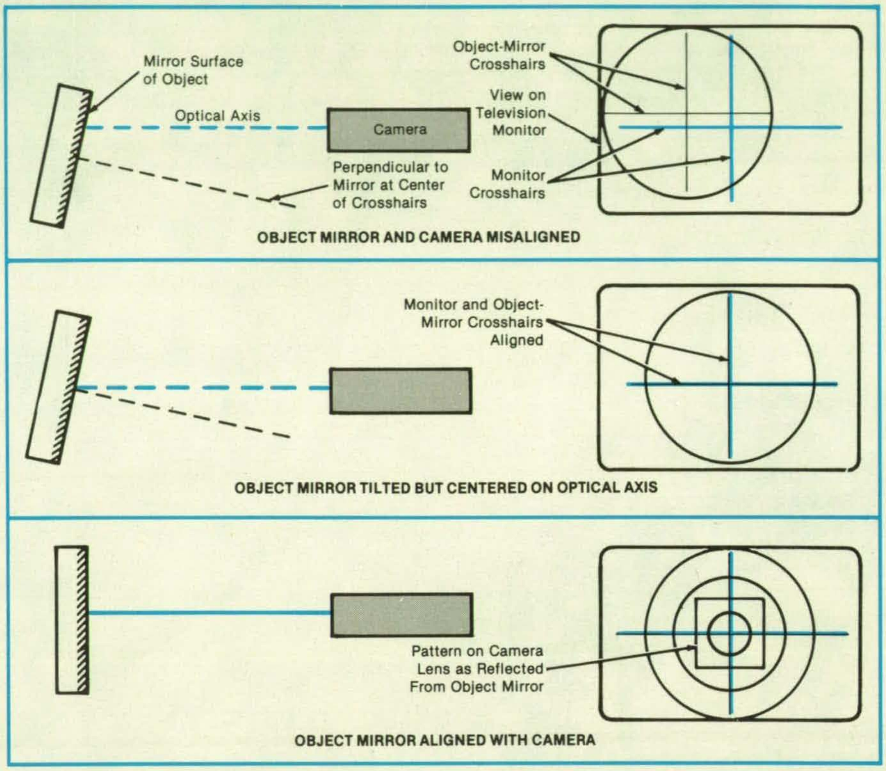
*Lyndon B. Johnson Space Center, Houston, Texas*

A video system enables an operator to align a remote manipulator with objects to be grasped. Unlike the alignment system that it is intended to replace, the new system does not rely on aligning protuberances on the objects. Consequently, it becomes possible to eliminate such protuberances and the mechanical interferences that they cause.

The end effector on the manipulator holds a television camera that views the object to be grasped. Crosshairs on the camera lens intersect at the center of the lens. The lens reticle also includes a circle and a rectangle centered on the optical axis. The object has a reflector on its surface, also with crosshairs at its center.

The remote-manipulator operator views the image from the camera on a television monitor, which displays another set of crosshairs that intersect at the point corresponding to the optical axis of the camera.

The operator moves the end effector to bring the three sets of crosshairs into alignment. Before the camera is centered on the reflector, two sets of crosshairs appear displaced on the monitor (see figure). When the camera is centered on the reflector but the surface of the reflector is not perpendicular to the optical axis of the camera, the crosshairs of the object in the television image align with the crosshairs of the monitor, but the television image (if any) of the crosshairs in the lens remains off center or out of sight. When the surface of the reflector is made perpendicular to the optical axis, the view of the crosshairs on the lens is reflected back along the optical axis into the camera, and these crosshairs then align with the others in the television image.




The **Display on the Television Monitor** reveals the orientation of the television camera with respect to crosshairs on a mirror on an object with which the camera is to be aligned.

The alignment system could be automated by using pattern-matching algorithms to control the orientation of the camera or object or both. With the addition of range-measuring instrumentation, the end effector could also be moved automatically to the object while the proper orientation is maintained.

*This work was done by Leo G. Monford of* **Johnson Space Center**. *For further information, Circle 108 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 18].. Refer to MSC-21372.*

# Gray-Scale Processing for Tracking of Welds

## Digital analysis of video images provides information for control of a welding robot.

*Marshall Space Flight Center, Alabama*

A real-time digital video-image-processing system contributes to the automation of weld-seam tracking. The tracking system makes no contact with the seam. A small television camera views the seam just ahead of the point currently being welded. The welding arc provides the illumination. Periodically, a frame grabber digitizes the video image and stores it in a computer memory as gray-scale values. The seam is located by analyzing Hough-transform arrays of derivatives of digitally-filtered image data. The information on the location and orientation of the seam is used as feedback by a welding robot to correct deviations of the electrode from the seam as welding continues.

Standard image-processing techniques are used in the early stages of the analysis. First, the image data are filtered by a 3-by-3 convolution. First and second derivatives of the filtered data are calculated in the direction perpendicular to the direction of motion of the torch. The derivative data are then compared with threshold values and used to calculate three Hough-transform arrays. The first and second arrays corres-

pond to first-derivative data above and below a threshold, respectively; the third array, to second-derivative data below a threshold.

The three Hough arrays are examined to determine the angle having the most entries. That angle corresponds to the angle of the seam in the image. The column in each of the arrays corresponding to that angle is then scanned for the locations of peaks. A set of pattern-matching rules is used to locate specific patterns of peaks. These correspond to various joint profiles; the location of the match indicates the location of the joint in the image.

The system can locate the seam between two metal parts even if they are shiny, and it can detect a smaller gap than could previous systems. The location and angle of the seam can be determined without any advance information. The seam-tracking algorithm is more robust than the previous ones, both in finding the seam and in deciding whether the seam has been found.

*This work was done by David A. Gutow of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 18]. Refer to MFS-29433.*

# DMSK Receiver for Mobile/Satellite Service

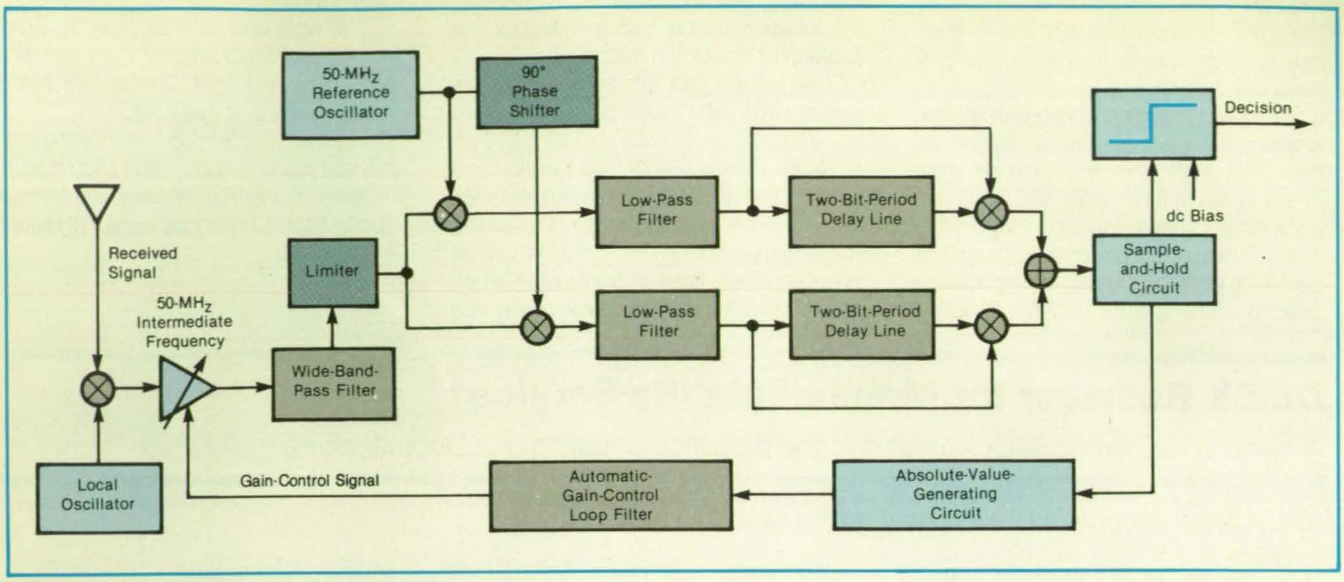
A low-bit-rate demodulator operates in the presence of fading and Doppler shifts.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A receiver for 2.4-kbit/s differential minimum-shift keying (DMSK) and Gaussian minimum-shift keying (GMSK) is suitable for communication between land-mobile stations via geostationary satellites. Operating on a phase-shifted signal in the 800-MHz band, in the presence of fading and Doppler frequency shifts, the receiver is compact, makes efficient use of the frequency spectrum, and wastes little power. The receiver design can be implemented in very-large-scale-integrated circuits.

The incoming signal is shifted to an intermediate frequency of 50 MHz, wide-bandpass filtered, amplitude limited, then mixed with in-phase and 90°-phase-shifted signals from a 50-MHz voltage-controlled oscillator (see figure). The in-phase and quadrature mixer products are low-pass filtered at baseband and sent to "two-bit" differential detectors — so called because each mixes its input signal with the same signal delayed by two bit periods — to produce an output indicative of the difference in phase between the signal values at those two times.

The problem in receiver design is to assure that the phase detector makes the correct decision ($\pm\pi$ or 0) concerning this phase difference. The phase-shift error is minimized by operating the two-bit detectors at baseband rather than at the intermediate frequency. The low-pass filters in the in-phase and quadrature signal paths have a Gaussian characteristic and a peak-to-peak delay differential of 17 $\mu$s within the passband. (A differential as small as this would be difficult to achieve at the intermediate frequency.) The maximum peak-to-peak differential delay of the delay line is only 5 $\mu$s. As a result, the maximum anticipated phase error at the frequency-




The **Basic DMSK Receiver Design** relies on baseband rather than intermediate-frequency processing of the in-phase and quadrature signal components because the phase errors due to differential delays are smaller at baseband. In the prototype receiver, the basic design shown here is augmented with automatic frequency control to correct frequency errors.

shift-keying tone frequency of 600 Hz is only 4.7°.

The performance of the receiver was measured in the presence of thermal noise. A plot of the measured error rate as a function of the ratio of bit energy to noise energy closely followed the prediction of previous authors for the ideal case.

The error performance was measured in the presence of Rayleigh fading with a Doppler frequency of 20 Hz and Rician fading with a Doppler frequency of 72 Hz and a line-of-sight-to-multipath ratio of 10. The irreducible-error rate was also measured and plotted for a Doppler frequency of 72 Hz and a range of line-of-sight-to-multipath ratios. At a ratio of 10, the irreducible-error rate is $10^{-6}$, which is well below the network requirement of $10^{-3}$ for digital communications.

Receivers of this type are known to be sensitive to large frequency offsets, and tests confirmed that the performance of this receiver is degraded severely by frequency errors larger than 20 Hz. To overcome this deficiency, an automatic-frequency-control loop was added; this re-

duced the frequency error to a negligible level. The cost of the frequency-control loop to the static performance of the receiver is about 0.5 dB.

*This work was done by Faramaz Davarian, Marvin K. Simon, and Joe T. Sumida of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 94 on the TSP Request Card. NPO-16659*

## Books and Reports

**These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.**

### Automatic Frequency Control for DMSK Receiver

Performance is analyzed theoretically and experimentally.

A report discusses the performance of the automatic frequency-control (AFC) subsystem of the differential minimum-shift-keying receiver described in "DMSK Receiver for Mobile/Satellite Service," NPO-16659, which appears in this issue of *NASA Tech Briefs*. It describes the efforts to quantify the behavior of the system during the acquisition of the carrier signal; these include a theoretical analysis leading to a numerical simulation, and measurements of the performance of the receiving equipment.

The AFC subsystem was added because the receiver has a small tolerance for frequency error. Since it has to operate in digital communications in which the data are transmitted in short bursts (packets), the receiver must be able to acquire quickly the carrier frequency of the transmitted signal. However, the design features that enhance rapid acquisition tend to degrade steady-state performance. Therefore, it is necessary to quantify the acquisition behavior of the AFC subsystem to optimize it for the intended signal parameters and receiving system.

The analysis begins with the input/output equations of the AFC loop, which is assumed to contain a resistor-and-capacitor low-pass filter. This is followed by a discussion of the nonlinear characteristic of the AFC loop, beginning with the sinusoidal dependence of the error voltage on a linear combination of the frequency error, the phase modulation due to intersymbol interference, and the phase modulation due to noise.

The report then presents a recursive equation that can be used to simulate numerically the performance of the nonlinear loop. A computer program based on this equation gives a sample of the output frequency of the voltage-controlled oscillator (VCO) of the AFC loop during a bit period. Next, an analysis of the steady-state behavior is based on the loop input/output equations and on the assumed loop-filter characteristics. The steady-state frequency error is shown to equal the difference between the input and VCO rest frequencies, divided by a closed-loop gain factor.

A numerical simulation was conducted for a system with a signal-to-noise ratio of 10 dB, a transmission rate of 2,400 b/s, a loop two-sided noise bandwidth of 34 Hz, a first-order loop filter with a time constant of 0.11 s, a loop-amplifier gain of 8, ideal bit synchronization, and an initial frequency error of 150 Hz. The simulated loop corrected for two-thirds of the initial frequency error in about 20 ms. By 40 ms, the error was down to about 20 Hz. The steady-state frequency error was 18 Hz (the predicted value was 16 Hz), with a standard deviation of 3.4 Hz.

A receiver with characteristics similar to those in the simulation was built and tested. The performance after acquisition times of 20 and 40 ms resembled the simulated performance. Bit-error measurements were also made and compared with theoretical values as functions of the signal-to-noise ratio. The 20-ms performance was about 0.7 dB inferior to the steady-state performance, which in turn was about 1.4 dB inferior to the ideal performance in the range tested. The theoretical pull-in frequency range of the AFC loop was 300 Hz, but noise reduced the range to 250 Hz.

*This work was done by Faramaz Davarian and Joe T. Sumida of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "An Automatic Frequency Control (AFC) System for Minimum Shift Keying and Binary FM Signals," Circle 36 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17021.*

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# Physical Sciences



## Calibration-Tube Dewar

Melting ice keeps the temperature near 0°C for about 1 day.

*Ames Research Center, Moffett Field, California*

A container maintains a reference material for gas chromatography at a constant temperature for extended periods. The container was developed for holding peroxyacetylnitrate (PAN), a material that is unstable at room temperature but stable at 0°C. The container keeps a vial of PAN at this temperature by immersing it in a mixture of water and ice. Substances that undergo phase changes at other temperatures can be substituted for ice and water if different reference materials and storage temperatures are used.

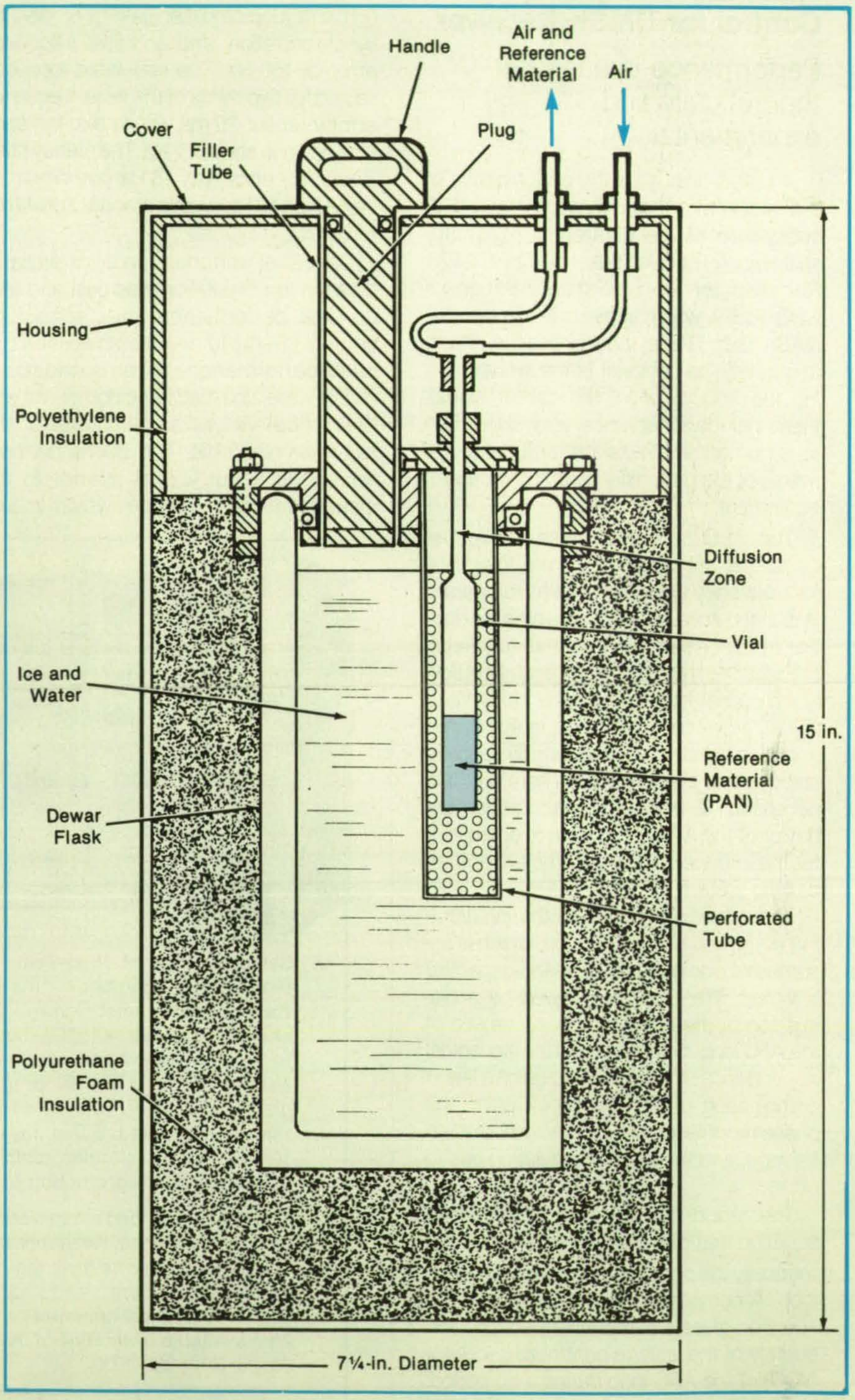
The container is used on research aircraft that collect and analyze air samples in the troposphere and stratosphere. In a recent research expedition, it provided PAN to calibrate an airborne chromatograph taking the first PAN measurements above the rain forests of the Amazon River basin. The container is a flight-rated component that is portable, compact, and rugged. It maintains PAN at 0°C for about 24 hours with a single charge of ice and water. A single vial of PAN remained stable during a 20-day stability test with morning and afternoon additions of ice.

The container consists of an aluminum housing with a stainless-steel Dewar flask suspended in polyurethane foam insulation (see figure). The ice/water mixture surrounds a 10-mL diffusion vial mounted on the cover of the flask.

The vial holds 5 mL of PAN in n-tridecane solvent. A metered flow of ultrapure air sweeps across the opening of the vial, mixing with PAN and carrying it to the chromatograph. The flow is diluted to provide the required concentration of PAN, ranging from 0.05 to 50 parts per billion by volume.

*This work was done by Donald B. Herlth of* **Ames Research Center** *and Dean P. O'Hara of San Jose State University. For further information, Circle 3 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 18]. Refer to ARC-12119.*




The **Perforated Tube Surrounds the Vial**, protecting it from damage by ice but allowing cold water to circulate around it. The plug with the handle is removable so that ice can be added through the filler tube. O-rings seal the joints around removable parts.

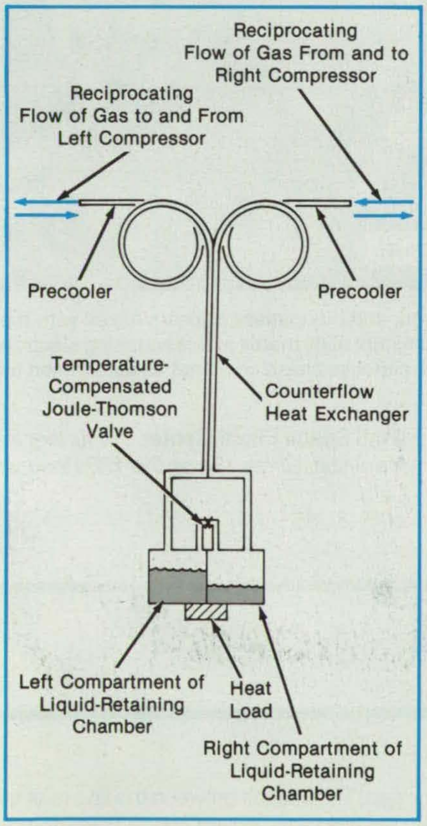
# Joule-Thomson Expander Without Check Valves

Cooling is effected by a bidirectional, reciprocating flow of gas.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A new type of Joule-Thomson (J-T) expander for cryogenic cooling requires no check valves to prevent the reverse flow of coolant. The new expander is therefore more reliable than the conventional J-T expander, which contains a network of check valves, each a potential source of failure.

The flow of coolant must be unidirectional in a conventional J-T expansion system. Coolant gas flows from a compressor through check valves (which ensure unidirectionality), a precooler, and the high-pressure side of a counterflow heat exchanger. The gas expands in a J-T valve, cooling a heat load. The expanded gas passes through the low-pressure side of the heat exchanger and another set of check valves before returning to the compressor.




**Gas Flows Alternately** from left to right and right to left. The heat load is cooled by evaporation of liquid from the left or right compartment, whichever is at the lower pressure.

In the new J-T expander, the flow of coolant alternates in direction. The counterflow heat exchanger consists of a mirror-image pair of gas lines soldered together (see figure). The high-pressure gas from a compressor on the left side flows through a precooler, the counterflow exchanger, the left compartment of a liquid-retaining chamber, and a J-T valve. Condensed liquid from the J-T expansion collects in the right compartment, while the expanded gas flows through the right line of the counterflow heat exchanger to the right compressor.

The direction of flow is then reversed. The right compressor pushes gas at high pressure through the right compartment, causing the gas to expand in the J-T valve.

Liquid collects in the left compartment, and gas passes to the left compressor.

The flow alternates left and right. The repeated flow through the J-T valve provides liquid to cool the heat load. Liquid accumulated in each compartment during each half cycle evaporates during the ensuing half cycle, removing heat from the load.

*This work was done by C. K. Chan and J. R. Gatewood of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 145 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17143.*

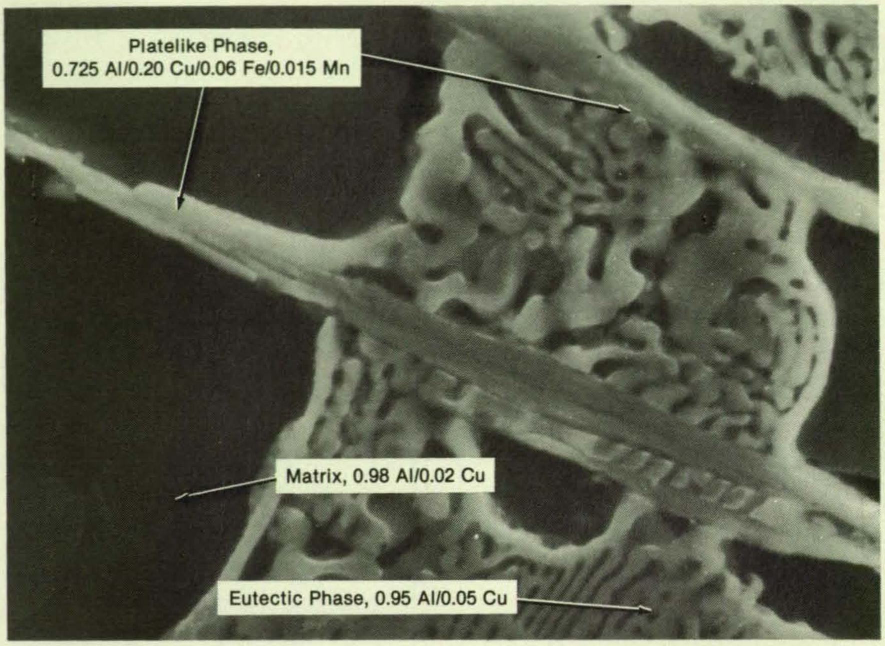
# Identification of Anomalies in Welds

## Advanced techniques are combined with conventional analytical methods.

*Marshall Space Flight Center, Alabama*

A combination of real-time radiography, scanning electron microscopy, and energy-dispersive spectrometry can identify enigmatic features in radiographs of welds where the standard tensile, hardness, and electrical-conductivity tests and visible-light microscopic and macroscopic examinations are insufficient by themselves. The new combination of techniques was applied successfully to variable-polarity-plasma-arc welds of 2219 aluminum alloy. The joints were subjected to penetration, fill, and weld-repair passes with 2319 aluminum weld wire.

Radiographs of the test welds showed anomalous white dots and lines. These anomalous features were then observed in a scanning electron microscope instrumented with an energy-dispersive spectrometer while the data were processed in real time. This combination of techniques showed that these regions consist of a platelike phase intermixed with the aluminum/copper eutectic (see figure). They also showed that the platelike phase is rich in copper (20 percent), iron (6 percent), and manganese (1.5 percent). These concentrations are many times greater than those in other parts of the weld.




A **Platelike Phase of Aluminum** with copper, iron, and manganese appears mixed with the eutectic phase and extends into the copper/aluminum alloy matrix in this scanning electron micrograph. The composition and nature of the platelike phase could not be determined by ordinary methods.

In general, the white lines were located in the zones of fusion between the penetration passes and the base metal. One of the white dots was identified as part of a penetration pass just beneath the zone of fusion between the penetration and fill passes.

*This work was done by David G. Knichen of Martin Marietta Corp. for* **Marshall Space Flight Center**. *For further information, Circle 134 on the TSP Request Card.*
*MFS-28285*

# High Temperature Gas-Gap Thermal Switch

## The flow of heat is varied at will.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A simple device can be set to allow heat to flow across a gap (switch "on") or to decrease the rate of transfer of heat to a relatively low value (switch "off"). The device — a gas-gap heat switch — operates at temperatures in the approximate range of 100 to 1,500 °C.

Although similar heat switches have been made for operation at lower temperatures, they rely on the variation of only the conductive component of the transfer of heat; the designs of these units do not provide for the suppression of the thermal radiation, which contributes significantly to the transfer of heat at temperatures above about 100 °C. Consequently, these switches cannot be turned "off" at higher temperatures.

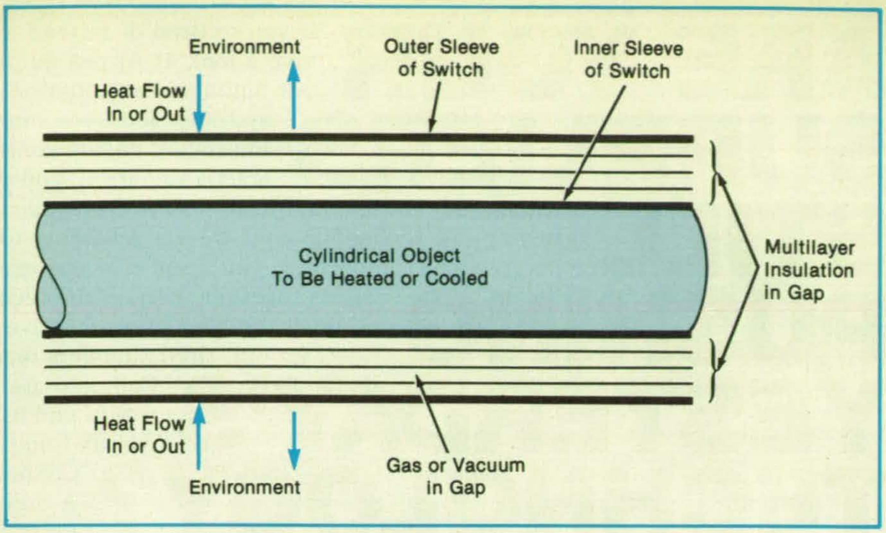
The principle of operation is illustrated in the figure, which shows a cylindrical version of the switch surrounding a cylindrical object that is to be thermally connected to or disconnected from the environment. The gap between the inner and outer sleeves of the switch is filled with layers of low-emissivity and low-absorptivity nickel, molybdenum, or zirconium foil to suppress the radiative transfer of heat across the gap. The spaces between the layers of foil are filled with woven quartz fibers to prevent the layers from touching, thereby reducing thermal conduction.

To turn the switch "off" — for example, to insulate the inner cylinder so that it can be heated, the gap in the switch is evacuated. To turn the switch "on" — for example, to allow the inner cylinder to shed its heat to the environment, the gap in the switch is filled with a gas. Any of a large number of gases can be used, such as helium, hydrogen, nitrogen, and argon. The pressure of the gas in the gap has to be on-

ly about 1 torr (about 130 Pa) to provide substantial conduction of heat across the gap.

The vacuum to turn the switch "off" can be provided by an ordinary laboratory vacuum pump. A more novel approach that requires no moving parts would involve the use of a sorption pump to control the pressure in the switch. A bed of sorbent material (charcoal, zeolite, hydrides, or oxides) would be heated to drive the gas into the gap or cooled to absorb the gas from the gap at low pressure.

An experimental switch was made with a gap 0.095 in. (2.41mm) wide filled with 5 layers of 0.001-in. (0.025-mm) nickel foil. When tested at temperatures of 300 to 650 °C, using nitrogen as the heat-transfer gas and a cryopump as the source of the vacuum, the switch exhibited a switching ratio of 16. The switching ratio is defined as the ratio of thermal resistance in the "off" state to the "on" state. Calculations show that a decrease in the width of the gap to 0.05 in. (1.27 mm), coupled with the use of helium instead of nitrogen, should increase the switching ratio to 400.




The **Central Cylindrical Object** is thermally connected to (or disconnected from) the environment by filling the gap between the inner and outer sleeves of the switch (or evacuating the gap) to increase (or decrease) the thermal conduction across the gap.

*This work was done by Steven Bard of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 46 on the TSP Request Card.* NPO-17163

# Carbon Sorption Cryogenic Regenerator

Lower temperature and longer life are expected.

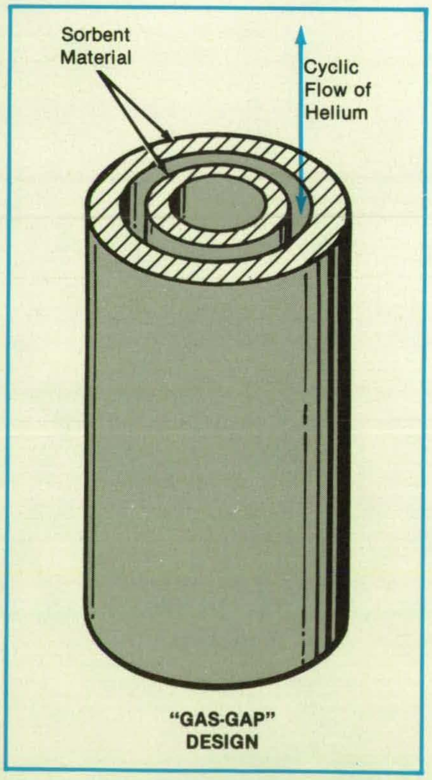
*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed liquid-helium refrigerator would include a regenerator filled with carbon sorbent made from Saran (or equivalent) polyvinylidene chloride. The new material should result in lower operating temperatures and longer times between maintenance than those of comparable refrigerators containing other regenerators.

Typical refrigerators based on the Gifford-McMahon or Stirling cycles include regenerators, which act somewhat like thermal capacitors for the helium working fluid. The efficiencies of these units decrease markedly as the temperatures decrease below 15 K, and they become inoperative below about 9 K due to the loss of volumetric heat capacity at such low temperatures. To reach lower temperatures, it is presently necessary to expand the helium through very tiny Joule-Thomson (J-T) valves, which eventually become clogged with oil from the helium compressors and thus require maintenance after approximately 2,000 h of operation.

The calculated volumetric heat capacity of the pressurized-helium/Saran (or equivalent) carbon system is about 1 J/(cm$^3$ • K) at 4 to 15 K. This is much greater than that of any other sorbent used thus far and should make it possible to attain operating temperatures of 4 K without the use of Joule-Thomson valves. Thus, the mean time between maintenance episodes would be increased to that of long-life oil-lubricated helium compressors — about 20,000 h.

The sorbent material is made by slowly heating polyvinylidene chloride to a temperature of 700 °C under vacuum or nitrogen. The material becomes pyrolized, and all elements except carbon are driven off, leaving a dense charcoal filled with microscopic pores of nearly uniform size. Unlike ordinary activated charcoal, this material is continuous and can be machined.




The **Sorbent Material** can be machined to various configurations to fit inside the cylindrical regenerator can. A particular configuration is chosen with regard to its heat capacity, pressure drop, and rate of sorption.

Helium, which is the only material that has a high specific heat below 10 K, is adsorbed in great quantities into the microscopic pores. This sorption regenerator is then capable of storing great quantities of heat between each compression/expansion cycle and is expected to allow efficient regeneration cooling down to 4 K. The very large surface area of the regenerator is much less subject to contamination than that of the tiny J-T expansion valve in of liquid-helium refrigeration.

In a proposed configuration of the regenerator (see figure), helium flows in the gap between two concentric cylinders of the sorbent material. Because the heat conductivity of the sorbent is much greater than that of the compressed helium alone, the sorbent can be made relatively thick to increase the heat capacity.

*This work was done by Jack A. Jones, S. Walter Petrick, and Michael J. Britcliffe of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 161 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17291.*

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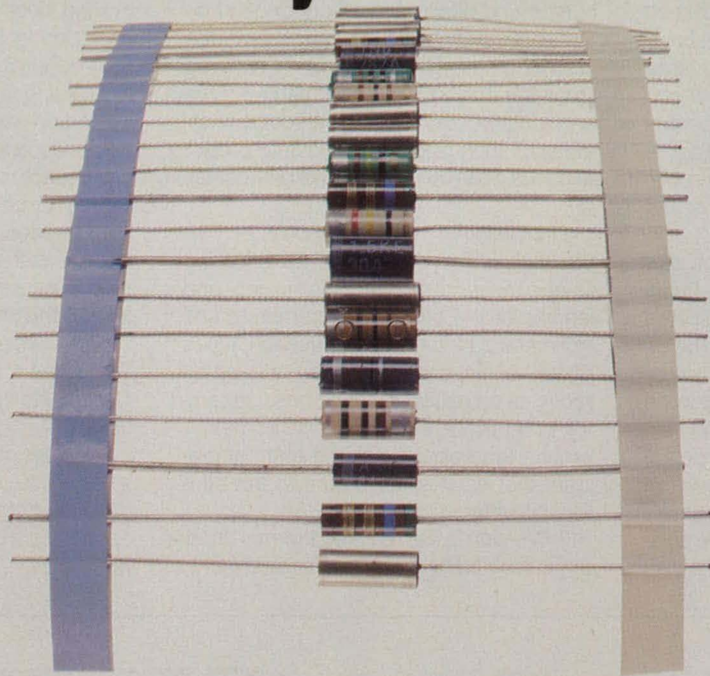

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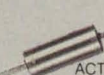


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**Circle Reader Action No. 529**

# Phase Separators and Fountain-Effect Pumps for He II

Fused-glass microchannel arrays for use as HE II phase separators and fountain-effect pumps.

*Marshall Space Flight Center, Alabama*

The characteristics of superfluid helium (He II) phase separators and fountain-effect pumps would be more predictable if the standard porous plugs (e.g., sintered metal-powder plugs) used in them were replaced by orderly fused-glass microchannel arrays. Three versions of microchannel devices have been proposed for use in low-gravity storage and cooling systems that contain superfluid helium.

The phase separators and pumps take advantage of the thermomechanical (fountain) effect peculiar to He II in restricted spaces like those in a porous plug. The effect causes the plug to confine a bulk supply of He II on one side, while allowing some flow via the evaporation of the helium in the pores. By creating a thermal gradient in the porous plug, the direction of flow can be reversed, turning the phase separator into a pump. However, the addition of heat is a disadvantage.

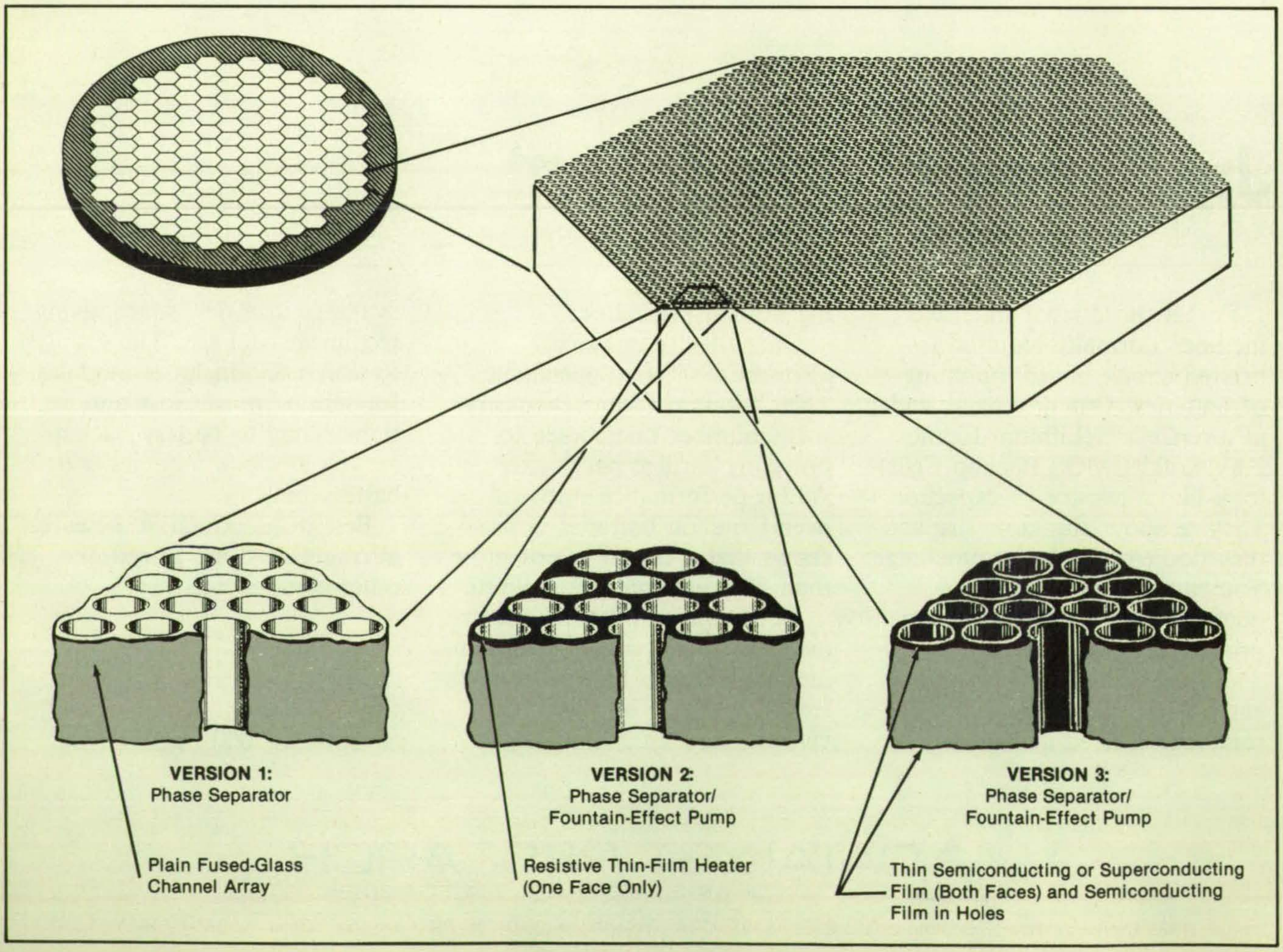
The operating characteristics of the pumps and phase separators depend on the configurations of the channels in the porous plugs. The channels in sintered plugs are irregular and have various sizes and roughnesses. The macroscopic properties of such plugs are difficult to predict and thus must be measured experimentally.

On the other hand, the pores or flow channels in fused-glass microchannel arrays are uniform, with diameters and lengths of the order of micrometers and millimeters, respectively. In version 1 (see figure), a microchannel array is used directly as a passive porous phase separator. In version 2, a resistive thin-film heater on one face establishes the thermal gradient that causes the device to act as a fountain-effect pump.

In Version 3, the required thermal gradient is created by using the Peltier effect to transfer heat across the array, thus removing heat from the He II supply and overcoming the undesirable addition of heat. A Peltier junction is formed by a semiconducting film on the microchannel surfaces and second semiconducting or superconducting film on both faces of an array. Each of the versions is in various stages of conception and investigation. The passage of electric current from one surface to the other in the appropriate direction causes heat to flow from one surface to the other.

*This work was done by Paul L. Whitehouse of* **Marshall Space Flight Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 18]. Refer to MFS-28243.*




**Microchannel Arrays** could be used as the basis for phase separators and fountain-effect pumps for superfluid helium.

# Materials



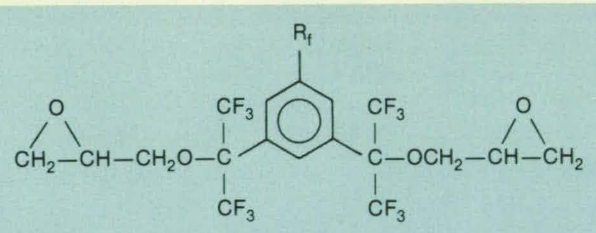
## Fluoroepoxy Adhesives Bond Fluoroplastics

Etching or other special preparation is unnecessary.

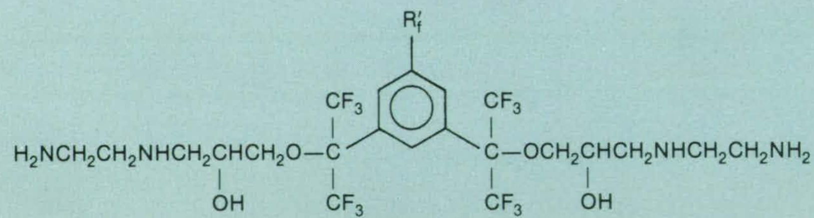
*Goddard Space Flight Center, Greenbelt, Maryland*

Experiments have shown that some fluoroepoxy compounds of high fluorine content adhere to fluoroplastics, without prior etching or other treatment of the fluoroplastic surfaces. Previously, fluoroplastics with high fluorine contents could be bonded with epoxies or other adhesives only after severe etching, usually by a corrosive sodium/naphthalene complex. The etching weakened the surface layers and made the bonds vulnerable to degradation by moisture, oxygen, and ultraviolet light.

A representative fluoroepoxy compound could be made from a fluorodiepoxide resin cured by an adduct diamine (see figure). The adduct diamine could be made by reacting the same or a different diepoxide with an excess of ethylenediamine. Other curing agents — for example, 3,3,4,4,5,5,6,6-octafluorooctamethylenediamine — could be used, as long as it is compatible with the particular fluoroepoxy resin.



FLUORODIEPOXIDE RESIN



ADDUCT DIAMINE CURING AGENT

These **Compounds Are Mixed With Each Other** in approximately stoichiometric amounts and react to produce fluoroepoxy compounds that adhere to fluoroplastics. The fluorine content is governed primarily by the selection of $R_f$ and $R'_f$, which are perfluoroalkyl groups of general formula $C_nF_{2n+1}$ (where n is an integer).

The use of fluoroepoxies is most advantageous in bonding polymers that have fluorine contents of 55 percent or more; for example, polytetrafluoroethylene (76 weight percent fluorine). Almost any of the variety of suitable fluorinated epoxy resins and curing agents can be selected. The main requirement is to obtain adherence without the need for treatment of the surface, and the experiments show that this is achieved by using an epoxy compound with a fluorine content of at least 46 weight percent.

While higher fluorine contents are clearly advantageous in fluoroepoxies used to bond fluoroplastics with high fluorine contents, they are less advantageous in fluoroepoxies used to bond fluoroplastics with lower fluorine contents. For example, in experiments on an ethylene/tetrafluoroethylene copolymer that contains 54.4 percent fluorine, a commercial nonfluorinated epoxy bonded somewhat more strongly [tensile strength of 743 $\pm$ 142 psi (5.12 $\pm$ 0.99 MPa)] than three fluoroepoxies [tensile strengths of 573 $\pm$ 160, 586 $\pm$ 188, and 567 $\pm$ 200 psi (3.95 $\pm$ 1.10, 4.04 $\pm$ 1.29, and 3.91 $\pm$ 1.38 MPa), respectively].

Depending on the specific parts to be bonded and the curing process desired, either or both the fluoroepoxy resin and curing agent chosen could be liquid or solid. For example, to make a laminate of large area, a mixture of solid resin and solid curing agent could be pressed between the layers to be bonded and heated to make the compounds react. In this case, one of the main requirements is that at some time during the process the fluoroepoxy compound be sufficiently liquid or at least able to flow under pressure and wet the surfaces of the fluoroplastic parts.

*This work was done by Sheng Yen Lee of* ***Goddard Space Flight Center****. For further information, Circle 59 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 18]. Refer to GSC-13072.*

## Soluble Aromatic Polyimides for Film Coating

Films are nearly colorless and soluble and exhibit good mechanical properties.

*Langley Research Center, Hampton, Virginia*

Because of their toughness, flexibility, and remarkable thermal stability, linear all-aromatic polyimides are excellent candidate film and coating materials for advanced electronic circuitry and wires. However, the inherent insolubility of these

polymers has somewhat limited their usefulness for electronic applications. A recent study determined the effects on solubility of changing isomeric points of attachment of phenoxy units in the diamine portions of several all-aromatic polyimides. Hexafluoropropane- and oxygen-containing dianhydrides (6FDA and ODPA) were used because of their known value in contributing to the stability of polyimides. The aromatic diamines used were varying isomers of oxydianiline (ODA) and bis(aminophenoxy)benzene.

Reactions of monomers yielded pale-yellow-to-colorless polyamic acid solutions. Tough, flexible, transparent films were produced by thermally converting the polyamic acids to polyimides at 300 °C in air. Films ranged in color from light yellow to essentially colorless, depending on thickness. The glass-transition temperatures ($T_g$) of films increased within each series of polymers as the linkages of the aromatic diamines were varied from all meta to all para. Polyimides prepared with 6FDA consistently displayed higher $T_g$ than did ODPA dianhydride-containing polymers with the same diamines.

Polymers prepared with ODPA dianhydrides were less soluble overall than those prepared with 6FDA, which were exceedingly soluble in the solvents used. The solubility increased with the incorporation of meta isomerism or ortho isomerism, which serves to create more "kinks" and dissymmetry in the polymer chains. The same trend was observed to a lesser degree in films containing ODPA.

Ortho isomerism appeared to have a greater effect on the solubility of ODPA films than did meta isomerism. Polymers prepared with 3,3′-ODA and 2,4′-ODA were found to be readily soluble at greater than 30- to 40-percent solids at room temperature in amide solvents. These polyimides are also readily soluble in chlorinated solvents and other low-boiling-temperature solvents. They can therefore be spray-coated onto desired substrates in the fully imidized form, eliminating the need to heat the substrates.

These soluble, phenoxy-linked polyimides yield tough, flexible, colorless-to-pale-yellow transparent films from amide or chlorinated solvents. Their potential for electronic applications should be excellent.

*This work was done by Anne K. St. Clair and Terry L. St. Clair of* **Langley Research Center**. *Further information may be found in NASA TM-89016 [N87-16911/NSP], "Soluble Aromatic Polyimides for Film Coating Applications."*

*Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.* LAR-13700

## Flexible, Polymer-Filled Metallic Conductors

Combined advantages of metals and polymers are exploited by advanced manufacturing techniques.

*Lewis Research Center, Cleveland, Ohio*

A procedure has been developed to make materials that are both flexible and reasonably good electrical conductors. Heretofore, electrical conductors for power and signal applications have been manufactured from pure metals and metal alloys because these materials possess the requisite electrical conductivity. Unfortunately, the repeated flexure of these metals in ordinary handling produces stress fatigue and, ultimately, mechanical failure.

Polymers that have much better flexure durability have been tried, but they are inadequate because of their very low electrical conductivity. Furthermore, because they have low thermal-decomposition tem-

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peratures, the polymers cannot be heated to a liquid state and mixed with molten metals to produce metal-organic materials that might have improved stress-fatigue properties.

In the new manufacturing procedure, a metal or a polymer sheet substrate is cleaned with a beam of energetic inert-gas ions to remove adsorbed gases and contaminants from its surface. After this cleaning, the substrate is coated by cosputter deposition of both a conductive metal and a flexible polymer. The substrate is then removed by either a mechanical or a chemical-dissolution technique, and the resulting flexible metal/polymer conductor can then be bonded at low temperature to conductor-surface contacts. Material thus produced exhibits both adequate electrical conductivity to convey power or signals and a flexibility that is superior to that of conventional metal conductors.

To demonstrate the beneficial properties of such a material, a mixture of 76 volume percent gold and 24 volume percent polytetrafluoroethylene approximately 8,000 Å thick was codeposited by ion-beam sputtering on a Kapton® polyimide substrate 0.0005 in. (12.7 μm) thick. The resulting laminate was capable of being bent (with the coating in tension) on a radius of curvature of 0.17 mm without either cracking or crazing the conductive coating. However, a 100-percent-gold coating of the same thickness was found to craze at a radius of curvature of 1.6 mm. Furthermore, the addition of the 24 percent of polymeric constituent raised the resistivity to only 3.7 times that of the pure gold.

*This work was done by Bruce A. Banks and Diane M. Swec of* **Lewis Research Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14161.*

# Low-Thermal-Expansion Filled Polytetrafluoroethylene

PTFE would be made thermally compatible with aluminum without changing its dielectric constant.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

According to a proposal, polytetrafluoroethylene (PTFE) would be manufactured with fillers and pores to reduce its coefficient of thermal expansion by a factor of 6 to match that of aluminum. The new material would retain the 2.1 dielectric constant of pure PTFE.

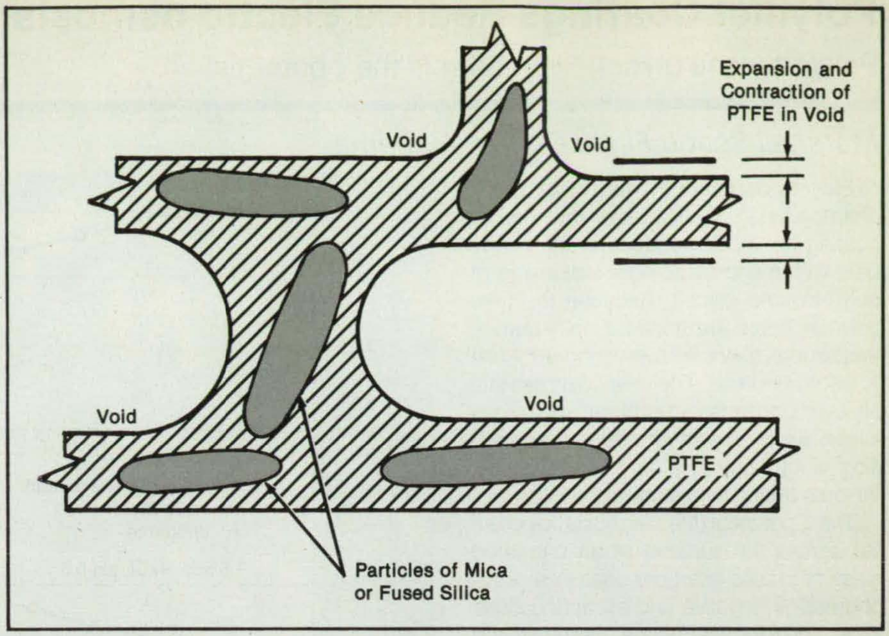
Heretofore, the great difference in expansion rates precluded the use of PTFE insulation in aluminum coaxial connectors, unless temperature could be restricted to a narrow range. Previous efforts to reduce the thermal expansion of PTFE also changed the dielectric constant, and the resulting material therefore could not be used as a direct substitute for pure PTFE in existing designs for 50-Ω coaxial connectors. For example, the addition of 50 percent mica or silica filler to reduce thermal expansion increases the dielectric constant to about 3.7. The introduction of micropores to reduce the expansion also decreases the dielectric constant to 1.5.

The new material combines the filler

and micropore concepts. The filler and micropores are expected to function synergistically; less filler and fewer micropores should be needed than if either were used alone to reduce the thermal expansion.

Particles of mica, fused silica, or other suitable low-expansion material would be blended with finely-ground hydrocarbon powder and powdered PTFE. The mixture would be heated to fuse the PTFE granules and the filler particles with the PTFE. With continued heating to a temperature not to exceed 550 °F (288 °C) (the maximum usable temperature of PTFE), the hydrocarbons would evaporate and escape from the PTFE matrix, leaving interconnected voids (see figure). Because the fillers and voids increase and decrease the dielectric constant, respectively, the amounts of each can be chosen to leave the dielectric constant unchanged.

From previous experience, it is known that the mica particles accept the compression forces created when the PTFE shrinks at low temperatures. At high temperatures, the PTFE becomes pliable, and the voids take up the excess volume so that the PTFE does not exert excessive tensile forces on the mica particles. With the blending of suitable proportions of the two fillers, it should be possible to balance these effects so that the filled, porous PTFE will have the correct dielectric constant and subject aluminum parts to little or no tensile or compressive stress as it shrinks or expands with falling or rising temperatures.




**Particles and Voids** embedded in the PTFE matrix function cooperatively. The particles take up compressive stress imposed by contracting PTFE, and the voids take up the expanding material. The particles increase the dielectric constant, while the voids reduce it.

*This work was done by Sanford S. Shapiro of Hughes Aircraft Co. for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 77 on the TSP Request Card.*
*NPO-17189*

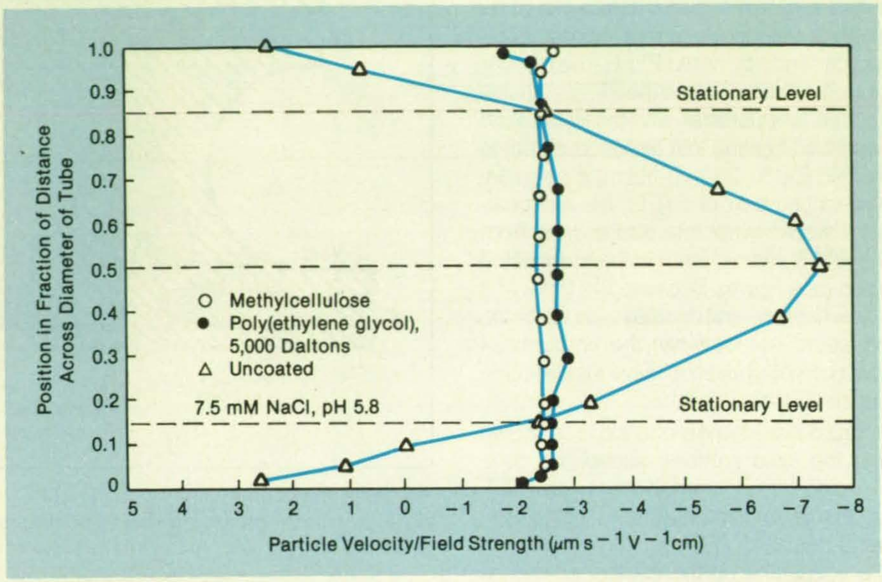
# Polymer Coatings Reduce Electro-osmosis

Poly(ethylene glycol) film controls the ζ potential.

*Marshall Space Flight Center, Alabama*

Electro-osmosis in quartz or glass chambers can be reduced or reversed by coating the inside surfaces of the chambers with monomacromolecular layers of poly(ethylene glycol). Because the new polymer coats are nontoxic, transparent, and neutral, they are advantageous for use in electrophoresis. The new coats are stable over long times. In contrast, methylcellulose, which is also effective in suppressing electro-osmosis on glass surfaces, desorbs during long storage periods.

The ζ potential (the electrostatic potential across the surface) of an untreated glass or plastic chamber used in electrophoresis is negative and attracts cations in an aqueous electrolyte. Because the cations are solvated, they entrain a flow of electrolyte as they migrate toward the cathode. This electro-osmotic flow interferes with the desired electrophoresis of particles suspended in the electrolyte.




The **Degree of Electro-osmosis** in coated and uncoated capillary tubes is indicated by the approximately parabolic curvature in the plot of axial particle velocity versus position across the diameter of the tube.

The polymer coat is attached covalently to the surface. It suppresses electrophoresis by reducing, or eliminating, the ζ potential. The degree of change in the ζ potential depends on (and can presumably be controlled by varying) the composition, structure, molecular weight, and surface density of the bound molecules.

The effects of electro-osmosis and the suppression of electro-osmosis during electrophoresis are best observed in narrow quartz capillary tubes with closed electrode ends, containing charged polystyrene-latex particles suspended in a dilute salt solution. As the particles migrate at a characteristic velocity per unit applied electric field (defined as the particle electrophoretic mobility), the combination of electrophoresis, the electro-osmotic flow of liquid along the wall, and the compensating return flow of liquid along the center of the tube causes a parabolic distribution of particle velocities across the tube. Only at the stationary level, where the electro-osmotic flow is zero, is the apparent mobility of a particle due entirely to electrophoresis.

The figure shows the results of such experiments in quartz tubes with various interior-surface treatments. A coat of methylcellulose and one of poly(ethylene glycol) of molecular weight 5,000 daltons produced nearly-flat velocity profiles, indicating nearly total elimination of electro-osmosis. A similar result was obtained with a poly(ethylene glycol) coat of molecular weight 20,000 daltons (not shown).

The new poly(ethylene glycol) coats should be useful in controlling ζ potentials over a wide range of pH and making beads of varying electrophoretic mobility. Chambers of varying electro-osmosis could also be produced for use in continuous-flow electrophoresis where optimum results are achieved by balancing electro-osmotic and Poiseuille flows. The suppression of electro-osmosis would enhance isoelectric focusing and analytical particle microelectrophoresis.

*This work was done by Blair J. Herren and Robert Snyder of* **Marshall Space Flight Center** *and Steven G. Shafer and J. Milton Harris of the University of Alabama and James M. Van Alstine of the Universities Space Research Association. For further information, Circle 153 on the TSP Request Card.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

*The University of Alabama, Huntsville*
*Department of Chemistry*
*Huntsville, AL 35899*
*or*
*Universities Space Research Association*
*American City Building, Suite 311*
*Columbia, MD 21044*

*Refer to MFS-26050, volume and number of this* NASA Tech Briefs *issue, and the page number.*

# Making Single Crystals of $B_4C$

Crystals precipitate from solution in copper.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Well-defined single crystals of boron carbide ($B_4C$) have been grown by slowly cooling melts containing $B_4C$ and copper. Crystals form both on the surface and in the interior of the melt.

In experiments, 36.8 weight percent of prereacted $B_4C$ and 63.2 weight percent of copper were placed in a boron nitride (BN) crucible and heated to about 1,900 °C in an atmosphere of argon and then held at that temperature for about 10 hours. The melt was cooled then at rates in the range of 7 to 10 °C per hour until the entire melt had solidified. After solidification, the material was cooled more rapidly to room temperature. To recover the $B_4C$ crystals, the copper was dissolved away with an aqueous solution of nitric and hydrofluoric acids.

Similar results are expected with other mixture percentages, temperatures, and cooling rates.

*This work was done by Robert S. Feigelson of Stanford University for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 81 on the TSP Request Card.*
*NPO-17255*

# Improving Thermoelectric Properties of (Si/Ge)/GaP Alloys

Annealing in steps increases the figure of merit.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A carefully-controlled heat treatment increases the thermoelectric figure of merit of hot-pressed GaP-doped Si/Ge alloy. Si/Ge alloys have been used in thermoelectric devices for more than a decade, during which experimental and theoretical work has continued with a view toward understanding and improving these materials.

The thermoelectric figure of merit, $Z$, is given by

$$Z = S^2/\rho\Lambda$$

where $S$ = the Seebeck coefficient, $\rho$ = the electrical resistivity, and $\Lambda$ = the thermal conductivity of the material being characterized. Prior research had shown that at grain sizes of less than 5 $\mu$m, the lattice thermal conductivities of heavily-doped Si/Ge alloys at a temperature of 1,000 K are reduced to about 35 percent below that of single-crystal Si/Ge. However, experiments with GaP-doped, fine-grain, n-type Si/Ge alloys also showed a decrease in $S^2/\rho$, with the result that there was no net increase in $Z$.

In the new heat treatment, GaP-doped Si/Ge is annealed at steps of increasing temperature: 1,200, 1,225, 1,235, and 1,275 °C. In three specimens tested, $\rho$ decreased, causing $Z$ to increase to values ranging from 1.0 to 1.1 mK$^{-1}$, about 30 percent higher than the previous value. Examination of the specimens by scanning-electron microscopy revealed the formation of a phase rich in Ge and Ga, an SiP phase, and particles of $SiO_2$. These new phases may be associated with the increase in $Z$.

*This work was done by Jan W. Vandersande and Charles Wood of Caltech and Susan Draper of Lewis Research Center for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 115 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17259.*

# Computer Programs



**COSMIC: Transferring NASA Software**

COSMIC, NASA's Computer Software Management and Information Center, distributes software developed with NASA funding to industry, other government agencies and academia.

COSMIC's inventory is updated regularly; new programs are reported in *Tech Briefs*. For additional information on any of the programs described here, circle the appropriate TSP number.

If you don't find a program in this issue that meets your needs, call COSMIC directly for a free review of programs in your area of interest. You can also purchase the 1988 *COSMIC Software Catalog*, containing descriptions and ordering information for available software.

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## Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make computer programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

## Fabrication Technology

### Unified Engineering Software System

A collection of computer programs performs diverse functions in prototype engineering.

NEXUS, the NASA Engineering Extendible Unified Software system, is a research set of computer programs designed to support the full sequence of activities encountered in NASA engineering projects. This sequence spans preliminary design, design analysis, detailed design, manufacturing, assembly, and testing. NEXUS primarily addresses the process of prototype engineering, the task of getting a single or small number of copies of a product to work.

The spinoff benefits of automating prototype engineering are significant because prototype engineering is a critical element of large-scale industrial production. The time and cost needed to introduce a new product are heavily dependent on two factors: (1) how efficiently required prototypes of the product can be developed and (2) how efficiently required production facilities, also a prototype engineering development, can be completed.

The extendability and unification of NEXUS are achieved by organizing the system as an arbitrarily large set of computer programs to which access can be gained in a common manner through a standard user interface. The NEXUS interface is a multipurpose interactive graphics interface called NASCAD (NASA Computer Aided Design). NASCAD can be used to build and display two- and three-dimensional geometries; to annotate models with dimension lines, text strings, and the like; and to store and retrieve such information related to a design as names, masses, and power requirements of components used in the design.

From the user's standpoint, NASCAD enables the construction, viewing, modification, and other processing of data structures that represent the design. Four basic types of data structures are supported by NASCAD: (1) three-dimensional geometric models of the object being designed, (2) alphanumeric arrays to hold data ranging from numeric scalars to multidimensional arrays of numbers or characters, (3) tabular data sets that provide a relational-data-base capability, and (4) procedure definitions to combine groups of system commands or other user procedures to create more powerful functions. NASCAD has extensive abilities to handle IGES format data, including proposed solid-geometry formats. This facilitates interfaction with other CAD systems.

NEXUS/NASCAD supports the activities encountered in various engineering projects as follows:

1. In preliminary design, geometric models can be built from points, lines, arcs, splines, polygons, drive surfaces, ruled surfaces, and bicubic spline surfaces. Geometric models can be displayed in any view (including removal of hidden lines and surfaces) to check design features.
2. In the analysis of design, geometric models and related data structures can be used to build a NASTRAN data deck. Calculated stress data can be added to model data structures and displayed as variations of color on the geometric model.
3. In detailed design, the geometric model is dimensioned and annotated, and manufacturing and assembly drawings are generated.

4. In manufacturing, the geometric model and related data structures developed by NASCAD can be used to build input for the APT program, which generates the cutter-location (CL) file that describes the required motions of a machine tool.
5. In assembly, a plan for a robot to put together or take apart (repair) a set of mechanical components can be generated on the basis of an IGES solid-geometrical description.
6. In testing, data from measurements can be correlated with predictions made during the design-analysis phase.

NEXUS/NASCAD is available by license for a period of 10 years to approved licensees. The licensed program product includes the source, executable code, command streams, and one set of documentation. Additional documentation may be purchased separately at any time. The NASTRAN and APT programs are distributed separately from the NEXUS/NASCAD system: Call or write to COSMIC for details.

The NEXUS/NASCAD system is written in FORTRAN 77 and PROLOG with command streams in DEC Control Language (DCL) for interactive execution under VMS on a DEC VAX-series computer. All of the PROLOG code deals with the robot strategy planner feature. A minimum recommended configuration is a DEC VAX 11/750 with 8 megabytes of real memory, 250 megabytes of disk storage, and a floating-point accelerator. For interactive graphics, NEXUS/NASCAD currently supports Tektronix 4114, 4016, 4115, and 4095 terminals; Lexidata Solidview terminals; and Ramtek 9400 terminals. Most features are supported on the VT 125, and the nongraphics features are available from a standard ASC II text terminal. The NEXUS/NASCAD system was first released in 1984 and was last updated in 1986.

*This program was written by L. R. Purves, S. Gordon, A. Peltzman, and M. Dube of* **Goddard Space Flight Center**. *For further information, Circle 140 on the TSP Request Card.*
*GSC-12900*

# Mathematics and Information Sciences

## Eliminating Tracking-System Clock Errors

Problems of redundancy and correlation are avoided.

The ORTHO computer program eliminates the effect of clock errors in the differential solutions for the positions of users of the Global Positioning System (GPS). The GPS is being developed by the U.S. Air Force and will use up to 24 NAVSTAR satellites to broadcast navigation messages for worldwide coverage. The normal positioning technique involves the use of one receiver, which receives signals from at least four GPS satellites. For higher accuracy, it is often necessary to use a differential technique that requires more than one receiver. A geodetic measurement in which all receivers are on the ground enables the determination of the relative locations of the ground sites.

The main application of the ORTHO program is in the elimination of clock errors in a tracking system based on the GPS. The measured distance (pseudorange) from a GPS receiver contains errors due to differences between the receiver and satellite clocks. The conventional way of eliminating clock errors is to take the differences between the pseudoranges between different GPS satellites and receivers. The Householder transformation used in this program performs a function similar to the conventional single differencing or double differencing. This method avoids the problem of redundancy and correlation encountered in a differencing scheme. It keeps all information contained in the measurements within the scope of a least-squares estimation. For multiple-transmit-

ter-and-receiver GPS tracking networks, this method is, in general, more accurate than the differencing technique.

This program is based in part on the assumption that the non-clock-measurement partial derivatives for the particular application were computed earlier by another program. With the partial derivatives and information to identify the transmitters and receivers as the input, the program performs the Householder transformation on the partial derivatives. The transformed partial derivatives are the output of the program and can be used as input to the filter program in the subsequent estimation process. Clock partial derivatives are generated internally and are not part of the input to the program.

ORTHO is written completely in FORTRAN 77 on the DEC VAX operating under VMS 4.5 and requires 805K of central memory. LINPACK, a public-domain subroutine package distributed by Argonne National Laboratory and IMSL subroutine library, is required. The program was released in 1988.

*This program was written by Jiun-tsong Wu and William I. Bertiger of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 158 on the TSP Request Card.*
*NPO-17098*

## Stellar Inertial Navigation Workstation

### Software and hardware are assembled to support specific engineering activities.

The Stellar Inertial Navigation Workstation (SINW) is an integrated computer workstation that provides systems and engineering support functions for Space-Shuttle guidance and navigation-system logistics, repair, and procurement activities. The workstation consists of personal-computer hardware, packaged software, and custom software integrated together into a user-friendly, menu-driven system.

The use of low-cost personal-computer equipment makes it economically feasible to dedicate the SINW to a limited set of applications. The system includes data-base and reporting functions for the scheduling of project activities, manpower, the preparation of correspondence, engineering design changes, items that require action by management, requirements table baseline, and the preparation of charts. With modification, the SINW could be used in other similar engineering activities in industry. The methodology and principles of the workstation implementation strategy can be applied in business and industry to develop similar workstations.

The software configuration of the SINW includes the following packages:
- IBM PC DOS (including the IBM LINK program);
- Microrim's R:base 4000 Database Management System, Extended Report Writer (XRW), and Program Interface (PI) Library;
- FPA's File Path Program;
- Seaware Corporation's Extended Batch Language (EBL) BAT program;
- IBM's Fixed Disk Organizer (FDO) program;
- Micropro's WordStar, CorrectStar, and Mail Merge;
- Lotus 1-2-3; and
- Hayes Smartcom Software.

The higher-level languages used for custom software programming include IBM's BASIC language and Microsoft Pascal.

The SINW program was developed in 1984. It is designed to operate on an IBM PC XT configured with one 360-kb floppy drive, one 10-Mb fixed disk, a monochrome CRT with Hercules HiResolution Board, an HP LaserJet printer, a Hayes SmartModem, and an HP 7475A Plotter.

*This program was written by W. Johnson, B. Johnson, and N. Swaminathan of Abacus Programming Corp. for* **Johnson Space Center**. *For further information, Circle 160 on the TSP Request Card.*
*MSC-21093*

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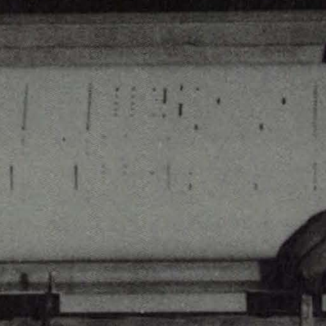

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# Mechanics



## Venting Gases With Minimum Loss of Heat

The design of a vent reduces radiative transfer of heat.

*Goddard Space Flight Center, Greenbelt, Maryland*

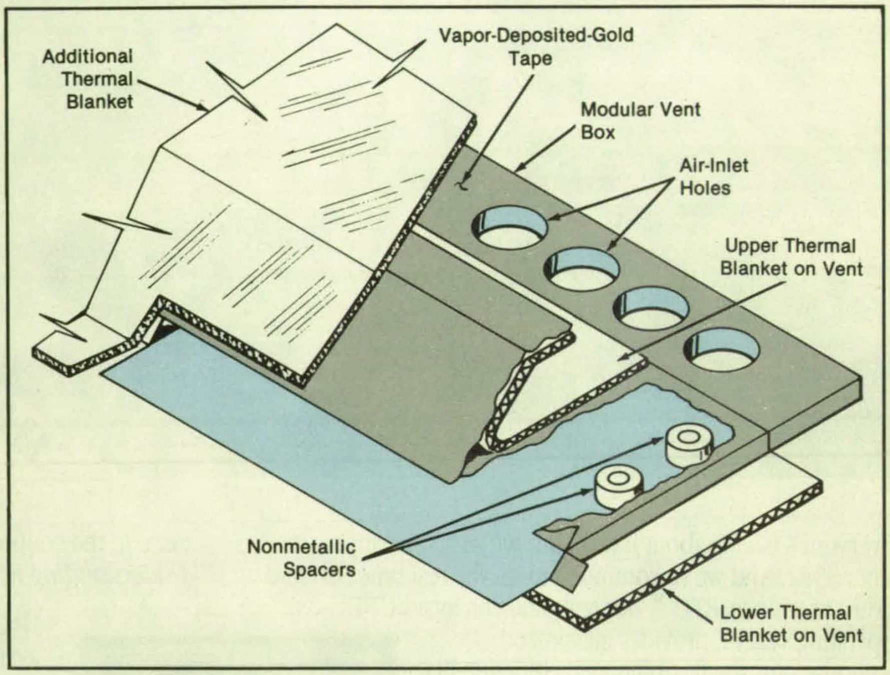
A venting system allows gases to escape while minimizing the loss of heat by radiation. By allowing the gases to escape, venting prevents an excessive buildup of internal pressure on the thermal blanket. Developed to permit outgassing from thermal-blanket-covered spacecraft during passage from the atmosphere of the Earth to the vacuum of space, the venting approach may be adaptable to thermal insulation in laboratory vacuum systems.

The system provides paths that allow gases to flow but occlude radiation from the inside to the outside. The system consists of vent modules, each folded from a sheet of polyimide laminate into a long, slender box (see figure). The box is pierced on top and bottom by four holes, which allow the free exchange of air or other gases between the inside and the outside. In a representative application, a box is 8.4 in. (21.3 cm) wide, 0.3 in (.76 cm) high, the holes are 1 in. (2.54 cm) in diameter, and nine boxes are used.

The exterior of the box is covered with polyimide tape on which a gold film has been vapor-deposited. The film ensures low infrared emissivity. Nonmetallic spacers of low thermal conductivity are positioned between the upper and lower surfaces of the box at six points. The spacers enable the mounting of the box on lugs and maintain dimensional stability under pressure loads resulting from the inflow and outflow of gases.

The outer surfaces of the box are covered with multilayer thermal blankets. Each blanket consists of 10 layers of aluminized polyimide interleaved with polyester netting.

*This work was done by James R. O'Coin and Joseph Genovese of United Technologies Corp. for* **Goddard Space Flight Center**. *For further information, Circle 70 on the TSP Request Card.* *GSC-13133*




The **Polyimide Box** serves as a modular vent. Many such modules can be combined to suit the gas-flow requirements of the equipment. Indirect flow paths, external thermal control film, and thermal blankets reduce the radiative loss of heat from the interior.

## Measuring Thermal Conductivities of Rough Specimens

Cost is reduced and accuracy and repeatability increased.

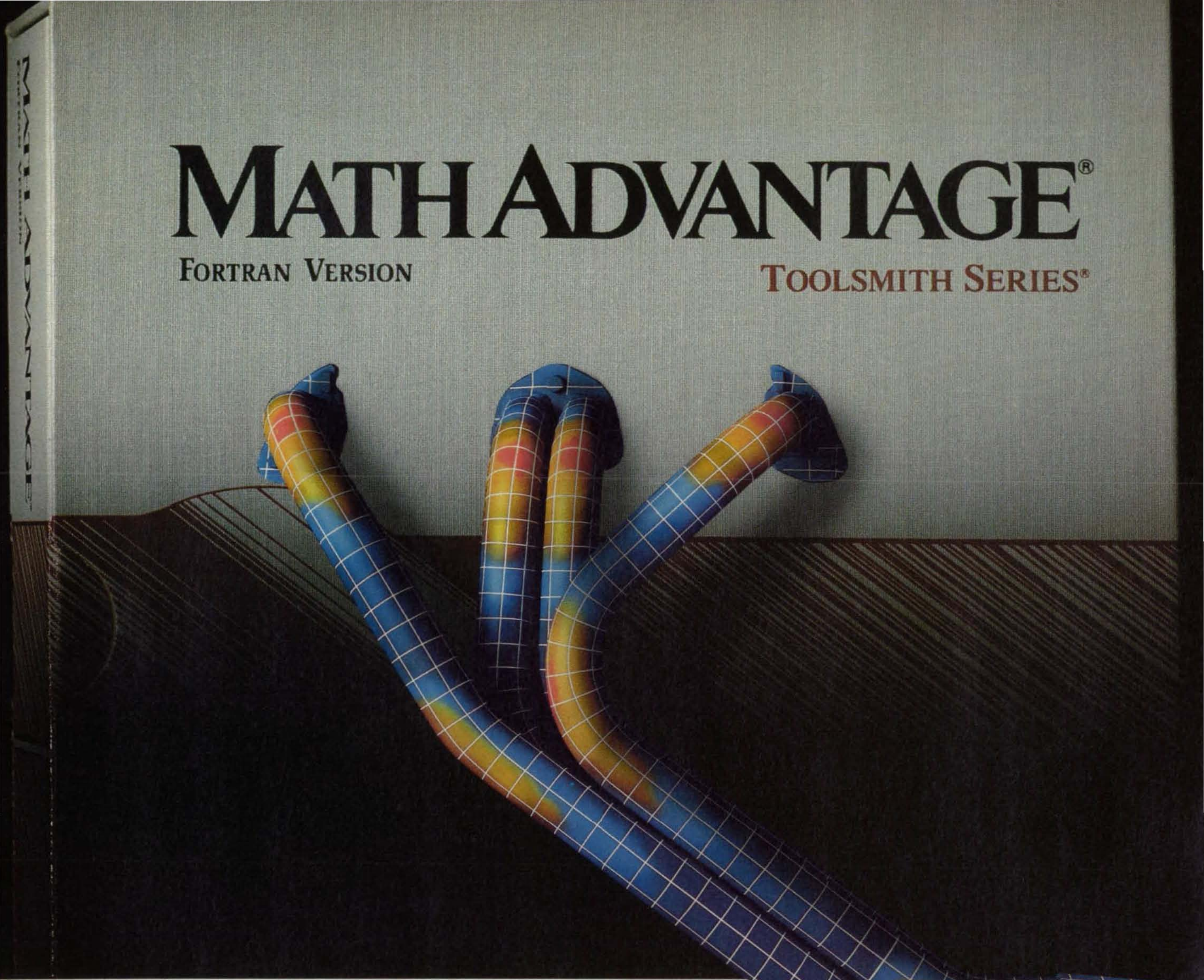
*Lyndon B. Johnson Space Center, Houston, Texas*

The thermal conductivity of an irregularly surfaced specimen can be measured more accurately and reliably than before by use of a heat-transfer adhesive that establishes contact between the specimen and the reference standards. The method is also useful when the specimen must be made up of fragments of material. The adhesive ensures good thermal contact to pieces that do not match the others in height (see figure).

Previously, the standard practice was to machine each specimen to a smooth, flat surface and load it in compression between the reference standards. The machining was costly and time consuming, and compressive loading did not ensure consistency of the contact thermal resistance.

The adhesive is cupric oxide cement, which has high thermal conductivity and bonds to many materials. It is usable at temperatures up to 500 °C and can be readily removed from glass or metal reference standards after the measurements are completed.

The assembled specimen and the reference standards are simply bonded together with the cement, which cures at room temperature. The reference standards are of identical size and shape and similarly instrumented with thermocouples. The sandwich structure consisting of the specimen between the two reference standards is placed between the upper and lower

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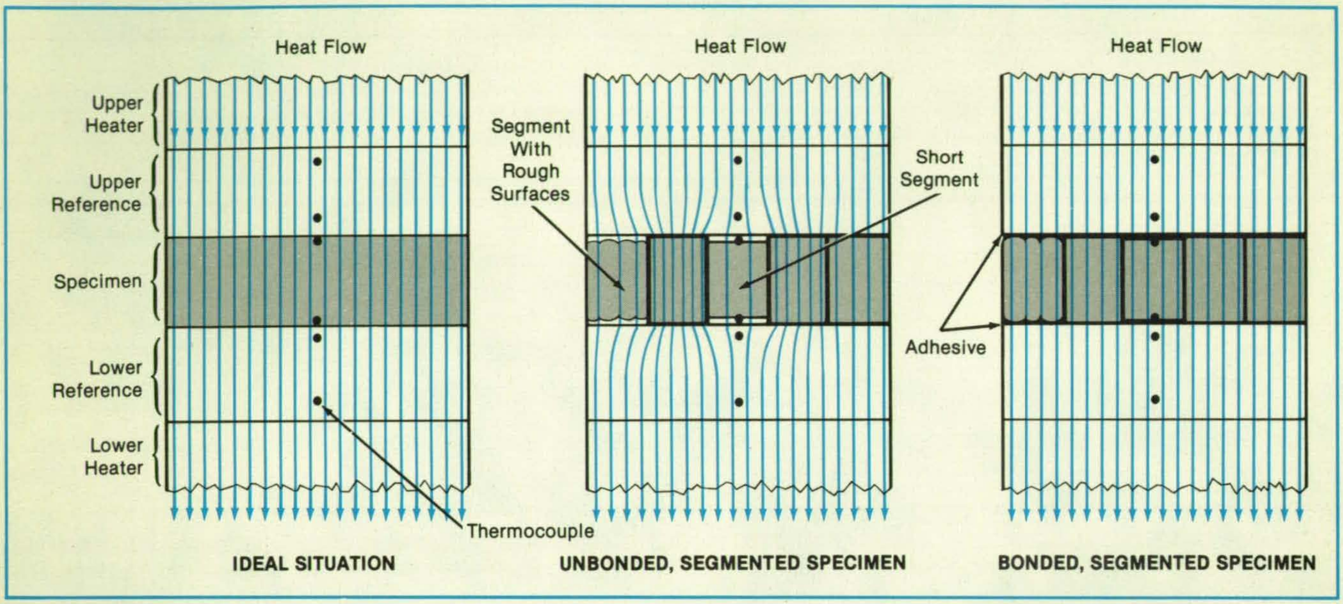
Circle Reader Action No. 570

heaters and mounted on a liquid-cooled heat sink. A guard heater is placed around the setup, and the space around it and between it and the apparatus is filled with alumina insulation.

The upper heater is set to a temperature higher than that of the lower heater to establish a controlled vertical temperature gradient in the sandwich. (The guard heater and the insulation nearly eliminate the radial gradient.) The temperatures of the specimen and of the reference standards are measured at various points. The thermal conductivity of the specimen is calculated from the temperatures and the distances between the measurement points.

In a comparison of measurements with and without the adhesive, the apparent thermal conductivities were higher in the adhesive-bonded specimens. For an advanced carbon/carbon composite material, for example, the thermal conductivity at room temperature was 147 Btu•in./h•ft$^2$ • °F (21.2 J/m• °C) for a bonded specimen and 49 Btu•in./h•ft$^2$• °F (7.1 J/m• °C) for an unbonded specimen.

*This work was done by Aloys H. Striepens and Chi-Wang Chang of Rockwell International Corp. for* **Johnson Space Center**. *For further information, Circle 157 on the TSP Request Card.*
*MSC-21333*




**Ideally, Heat Flows Uniformly** through a specimen (left). In rough-surfaced or unequally sized specimens, however, the heat-flow pattern becomes distorted, and temperatures at the measurement points do not accurately represent those throughout the reference standards and specimen. Filling the voids with a conductive adhesive restores the nearly uniform distribution of the heat flow.

# Double-O-Ring Plug for Leak Tests

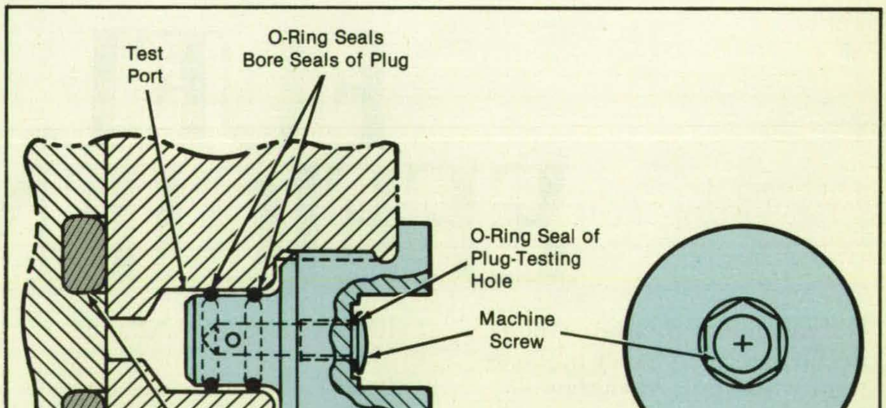
A verifiable redundant seal contributes to testing and assurance of safety.

*Marshall Space Flight Center, Alabama*

A pressure plug features redundant O-ring bore seals and an axial port that opens laterally into the space between the O-rings to enable testing of the seals (see figure). Designed to plug holes used to test the large O-rings of the Space Shuttle solid rocket boosters, the pressure plug might be useful to seal test or cleanout holes that are normally kept closed in hydraulic actuators, pumps, and other pressurized systems.

After the plug is installed and verified, a sealing ring — essentially an O-ring mounted as a washer — is placed in a recess in the plug and compressed by a screwhead. Thus, the screwhead and sealing ring act as a secondary seal in parallel with the outer O-ring.

*This work was done by James H. Greene of United Technologies Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*
*MFS-28222*




An **Axial Passage** in the plug is connected through a radial passage to the space between the O-rings. The opening is used to test the O-rings, then sealed with a smaller O-ring compressed by a machine screw.

# High-Capacity Heat-Pipe Evaporator

The cylindrical configuration increases the contact conductance.

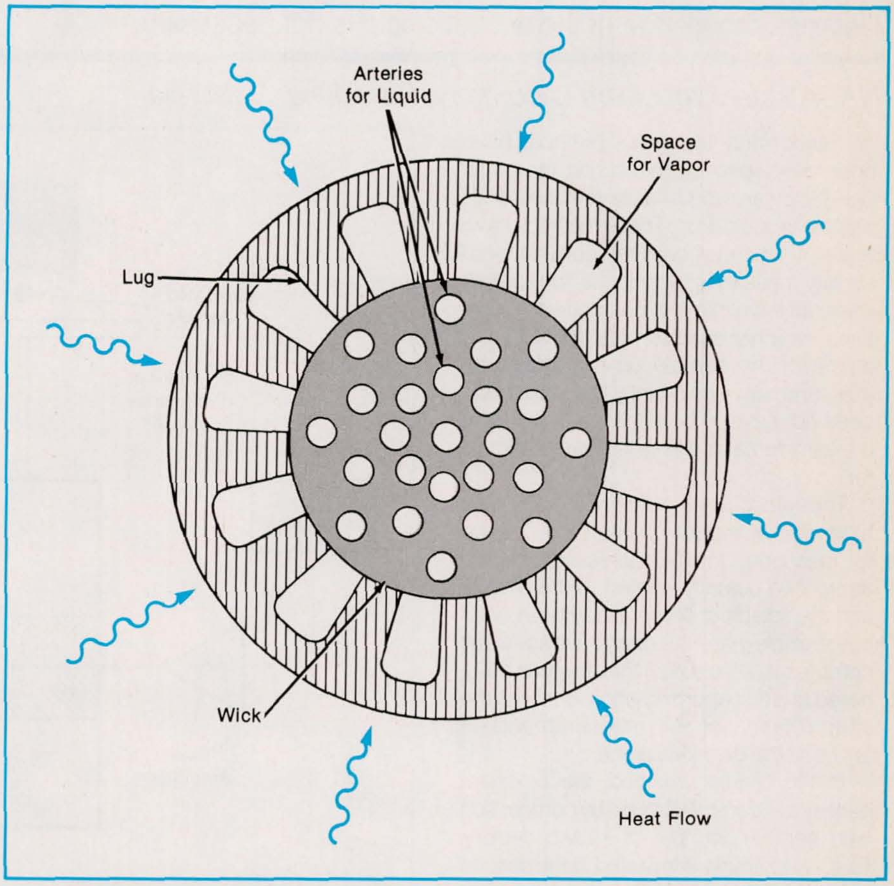
*Lyndon B. Johnson Space Center, Houston, Texas*

A heat pipe with a cylindrical heat-input surface has a higher contact thermal conductance than does a comparable one with the usual flat surface. Because the cylindrical heat absorber promotes the nearly uniform flow of heat into the pipe at all places around the periphery of the pipe, it helps to eliminate hotspots on the heat source.

The cylindrical heat absorber, an extruded aluminum tube with internal lugs, is the housing for the heat-pipe evaporator (see figure). A porous wick of polyethylene or sintered metal powder extends from the heat-pipe condenser into the round center channel of the evaporator tube, fitting snugly against the ends of the lugs. Arteries in the wick carry the working liquid from the condenser to the evaporator.

The liquid moves through the 80- and 120-μm-wide capillaries to the surface of the wick. There, heat from the lugs, conducted by the aluminum tube from the external heat source, causes the liquid to evaporate. The vaporized working fluid returns to the lower pressure condenser through the open passages between the lugs.

A cylindrical evaporator with a 1.75-in. (4.4-cm) diameter using ammonia as the working fluid would be able to transfer heat at a rate of 7,500 watts. This capacity is far higher than that of all known heat pipes now in operation.




**Lugs in an Aluminum Pipe** carry heat from the outer surface to the liquid oozing from the capillaries of the wick. The liquid absorbs the heat, evaporates, and passes out of the evaporator through the interlug passages.

*This work was done by J. A. Oren, R. J. Duschatko, F. E. Voss, and L. W. Sauer of LTV Corp. for* ***Johnson Space Center****. For further information, Circle 5 on the TSP Request Card.* *MSC-21272*

# Optimizing Locations of Nodes To Reduce Vibrations

The distribution of mass is modified to move the nodes to desired locations.

*Langley Research Center, Hampton, Virginia*

The current trend in the design of aircraft and spacecraft is to incorporate, in an integrated manner, various design requirements at an early stage in the design process. The conventional approach to meeting vibration requirements has been to correct a design for vibration, sometimes after a serious problem has been detected. Advances in technology are leading to more-complicated aircraft and spacecraft, with higher required speed and performance. Therefore, it is more important to include vibration requirements early in the design process.

Recently, the concept of modal shaping has been proposed as a method to reduce structural vibration. The current optimization technique deals with the placement of nodal points, which is related to modal shaping and consists of modifying the distribution of the mass of a structure to place the node of a mode at a desired location. The key to this optimization procedure is the analysis of the sensitivity of the locations of nodes, which provides straightforward expressions for the derivatives of the locations of the nodes.

The process of optimization uses added lumped masses on the structure as design variables to move the node to a preselected location. For example, the node can be moved to a point where low response amplitude is required or to a point that makes the shape of the mode nearly orthogonal to the distribution of force, thereby minimizing the generalized force and overall response. The formulaton of the optimization leads to values for added masses that adjust the location of a node while minimizing the total amount of mass required to do so

In one example, the node of the second mode of a cantilever box beam is relocated to coincide with the centroid of a prescribed distribution of force, thereby reducing the generalized force substantially without adding excessive mass. A comparison with an optimization formulation that directly minimizes the generalized force indicates that the appropriate placement of the node gives essentially a minimum generalized force.

This work was done by Howard M. Adelman of **Langley Research Center**, Jocelyn I. Pritchard of USAARTA-AVSCOM, and Raphael T. Haftka of Virginia Polytechnic Institute and State University. Further information may be found in NASA TM-87763 [N86-31069/NSP], "Sensitivity Analysis and Optimization of Nodal Point Placement for Vibration Reduction."

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LAR-13716

# Densitometry by Acoustic Levitation

## Detailed knowledge of the acoustic field is not necessary.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

"Static" and "dynamic" methods have been developed for measuring the mass density of an acoustically levitated solid particle or liquid drop. These methods have several advantages over conventional density-measuring techniques: the sample does not have to make contact with a container or other solid surface, the size and shape of the sample do not affect the measurement significantly, the sound field does not have to be known in detail, and the sample can be smaller than a microliter.

The "static" method (see Figure 1) is an extension of a prior gravitational method for measuring the "compressadensity," a composite quantity related to the density and the adiabatic compressibility. In practice, sample materials often have adiabatic compressibilities so low that they can be ignored to a first approximation, enabling the interpretation of the measurements in terms of the densities alone.

In the "static" method, the unknown density of a sample is found by comparison with another sample of known density. First, one sample is levitated to the desired height in the acoustic-levitation chamber, and the voltage on the acoustic transducers is recorded. The other sample is then acoustically levitated and the transducer voltage adjusted until the sample is held at the same height as that of the previous sample. Then assuming that the amplitude of the acoustic field is proportional to the transducer voltage, the density $\varrho_2$ of the unknown sample is related to the density $\varrho_1$ of the known sample by

$$\varrho_2 = \varrho_1(V_2/V_1)^2$$

where $V_1$ and $V_2$ are the transducer voltages for the known and unknown samples, respectively.

The "dynamic" method (see Figure 2) can be practiced with or without a gravitational field. The acoustic levitating field serves, in effect, as a spring instead of as a measure of gravitational force. The acoustic field is amplitude modulated by a few percent to make the sample oscillate about the equilibrium levitation position. The modulation frequency is varied until the

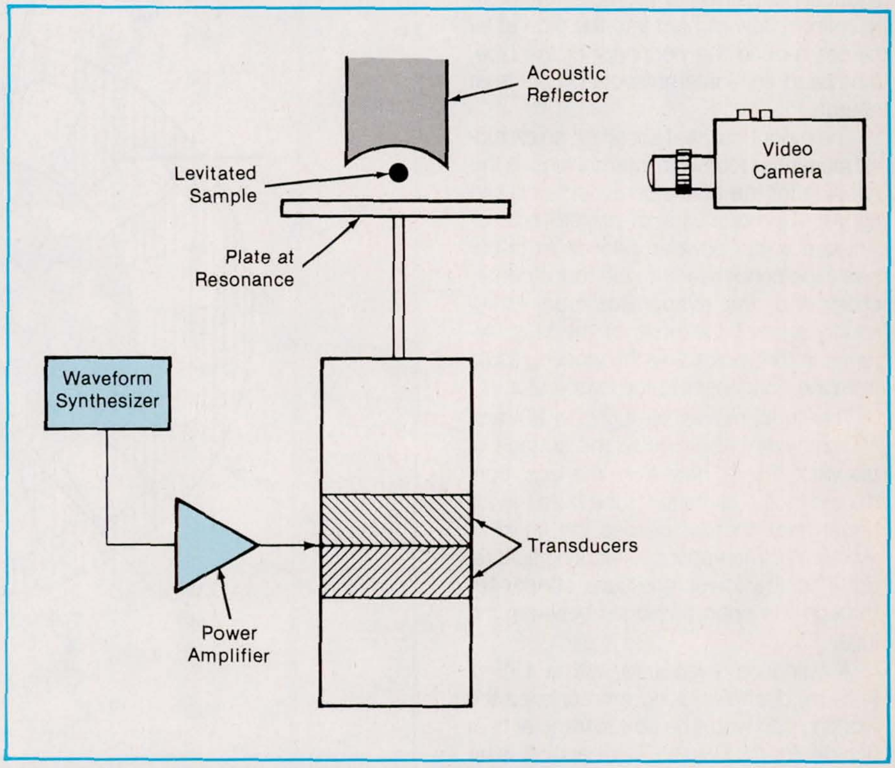



Figure 1. A **Sample Is Acoustically Levitated**, and the position of the sample is measured. The voltage on the transducers is recorded when the sample lies at the desired height.

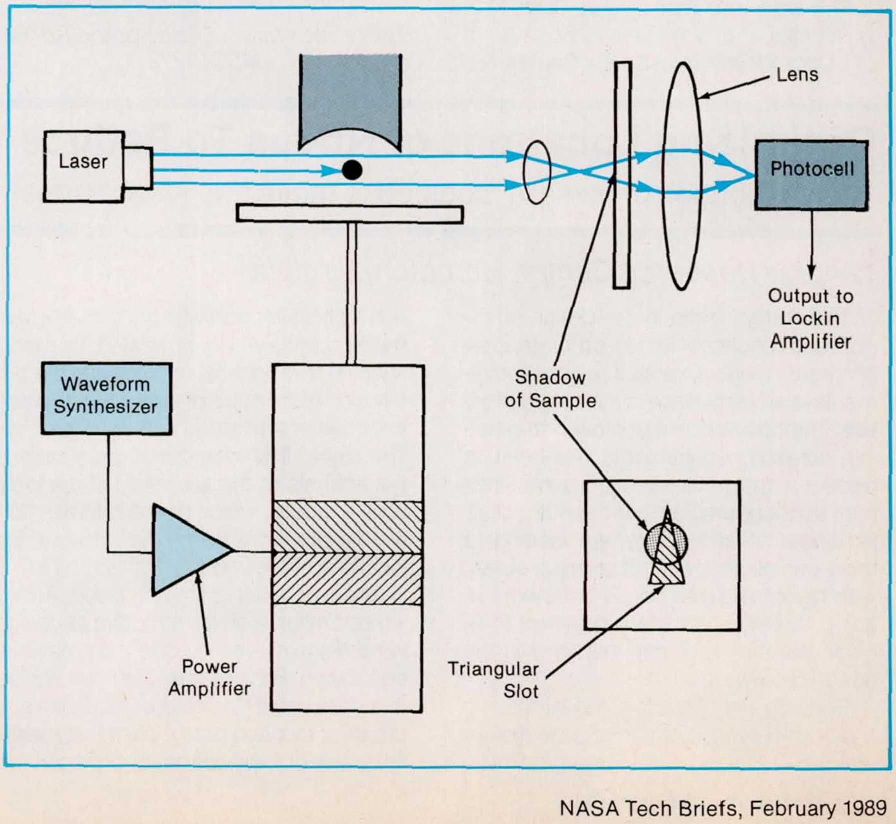



Figure 2. A **Levitated Sample Oscillates** about an equilibrium levitation position. The amplitude of oscillation is measured optoelectronically. The transducer voltage and oscillation frequency are also recorded.

resonant frequency of the oscillation is found, as indicated by the maximum amplitude of the excursions of the sample from the equilibrium position.

If known and unknown samples are levitated to the same equilibrium position and made to oscillate, then the density of the unknown sample can be found from

$$\varrho_2 = \varrho_1(V_2f_1/V_1f_2)^2$$

where $f_1$ and $f_2$ are the resonant frequencies of the known and unknown samples, respectively. In the absence of a gravitational field, the equilibrium position would not depend on the voltage, and the equation would be simplified to

$$\varrho_2 = \varrho_1(f_2/f_1)^2$$

*This work was done by Eugene H. Trinh of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 22 on the TSP Request Card.*
*NPO-16849*

# Borescope Inspects With Visible or Ultraviolet Light

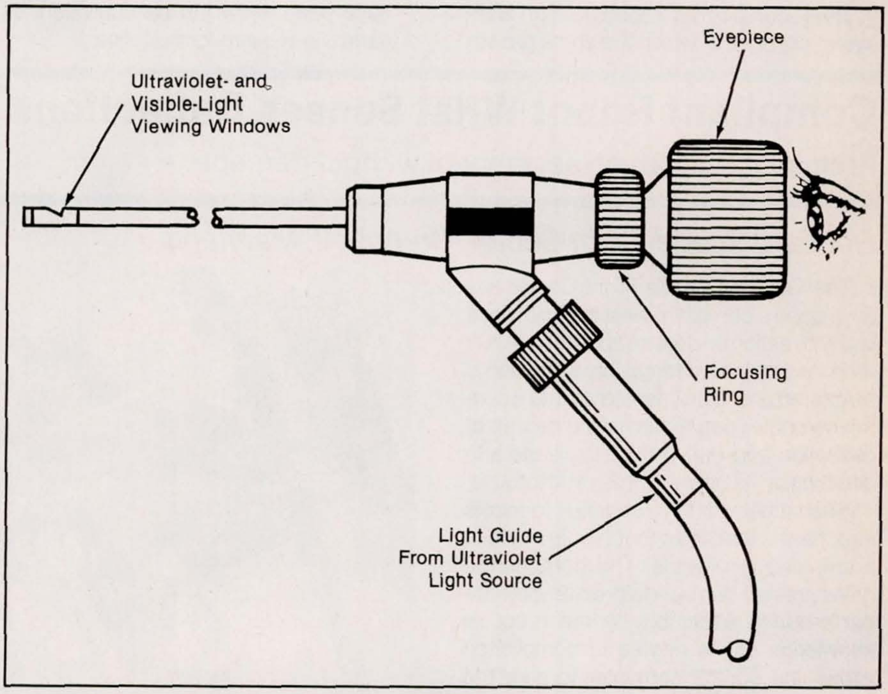
## Quartz optical fibers improve performance at ultraviolet wavelengths.

*Marshall Space Flight Center, Alabama*

A borescope can be used to inspect the interior of small-diameter tubing by both "white" (visible) light and "black" (ultraviolet) light. The borescope (see figure) employs quartz fibers to conduct the ultraviolet light as well as the visible light with high efficiency. In fact, the intensity of the ultraviolet output far exceeds that of other commercial borescopes of the same diameter. The ultraviolet output exceeds 1,000 $\mu W/cm^2$.

The borescope probe is 4 mm in diameter. It is intended for inspecting the interior surfaces of tubes with the aid of fluorescent penetrant dyes. The tubing, which is only 0.190 in. (4.83 mm) in inside diameter, is used in heat-exchanger coils. Gradient optics provide excellent images of internal defects illuminated with visible or ultraviolet light.

*This work was done by Orlando G. Molina of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*
*MFS-29369*




The **Thin Probe of the Borescope** enables inspection of small-diameter tubing.

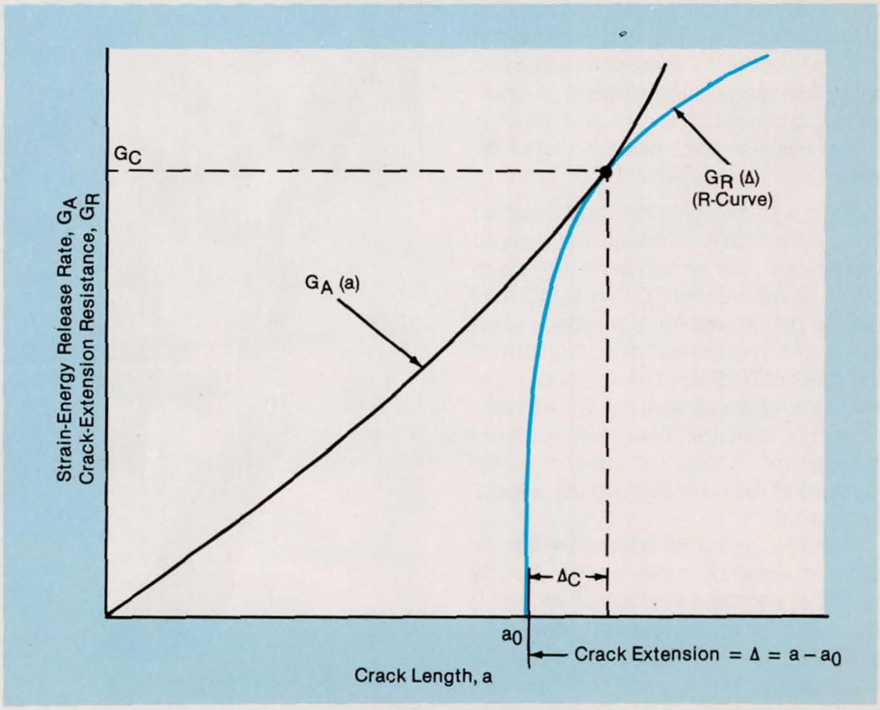
# Constructing R-Curves From Residual-Strength Data

## Old data can be exploited in a new concept.

*Lewis Research Center, Cleveland, Ohio*

A method has been devised for estimating a crack-extension resistance curve (R-curve) from residual-strength data on precracked fracture specimens. The method enables the inference of additional information from simple test results, and that information can be used to estimate the failure loads of more complicated structures of the same material and thickness.

The R-curve is one of the most powerful concepts available to the fracture analyst. For a specimen or structure of the same material and thickness in the same envi-




At the **Critical Stress,** the driving-force (strain-energy release rate) curve and the R (crack-extension resistance) curve are tangent. To the right of the point of tangency, the rate of release of strain energy exceeds the resistance to extension of the crack, and the specimen fractures.

ronment as those of a specimen for which a stress-intensity analysis is available, the R-curve can be used to predict failure loads. Now, with the new method, it is possible to reverse the process; that is, given a curve of fracture strength versus original crack size, the R-curve can be determined. This means that data from simple residual-strength tests run many years ago can now be used to predict the failure loads of more complicated structures like reinforced panels or cracked holes of the same material and thickness. Such data may be found in the literature or may exist in company files.

The R-curve is developed from an analysis of the point at which the crack growth becomes unstable (see figure). First, at a given point on the residual-strength curve, a function that represents the square of the fracture stress, $\sigma_c^2$, and its derivative, are computed and substituted into an equation that must be solved (usually numerically) for the critical crack extension, $\Delta_c$. Then $\Delta_c$ and $\sigma_c^2$ are used to calculate the fracture toughness $G_c$. The pair ($G_c$, $\Delta_c$) define a point on the R-curve. The process is repeated to obtain additional points on the R-curve.

The new R-curve-estimation method has been tested in three applications:
1. Several semiempirical fracture analyses have been shown to be equivalent to particular R-curve formulations.
2. R-curves were estimated to a useful degree from published residual-strength data for a variety of specimen configurations.
3. The method was used successfully in an ASTM blind round-robin program.

*This work was done by Thomas W. Orange of* **Lewis Research Center**. *Further information may be found in NASA TM-87182 [N86-18750/NSP], "Estimating the R-Curve from Residual Strength Data."*

*Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.* *LEW-14592*

# Compliant Robot Wrist Senses Deflections and Forces

Precise parts can be assembled without damage.

*Goddard Space Flight Center, Greenbelt, Maryland*

The Goddard Space Flight Center has developed a compliant wrist that will move in any direction and rotate about any axis in response to applied forces. Its deflection is calibrated and instrumented so that a control computer can measure the degree of deflection and derive the magnitude and direction of the applied forces and torques.

Such a compliant wrist brings to robots important capabilities that humans use in manipulating objects. The compliance helps prevent damage to precise, delicate parts during assembly by the robot. A knowledge of the degree of compliance allows the control computer to alter the robot's position to compensate for compliance-induced positioning deviations. The measure of the contact forces allows the system to perform a series of moves, using a force-sensing-search strategy, to determine and correct certain kinds of misalignments between parts being mated or demated.

Tests with the compliant wrist mounted on a computer-controlled manipulator have shown that certain parts with clearances on the order of 0.001 in. (0.025 mm) can be mated with force feedback when the initial errors in relative position are on the order of 0.25 in. (6 mm). Besides permitting error correction, the force/torque-sensing-control software can prevent damage to components and determine the success or failure in carrying out a specified operation.

As shown in the two figures, the compliant-wrist assembly consists of six identical rods that connect two plates. Each rod is essentially a spring-loaded piston. One plate, which serves as the base plate, is rigidly attached to the end of a robot arm and is connected to the rods through universal joints. The other or "compliant" plate is rigidly attached, usually by a gripper, to the object being manipulated and is connected to the other ends of the rods by spherical bearings. The "compliant" plate can move relatively to the robot arm in re-

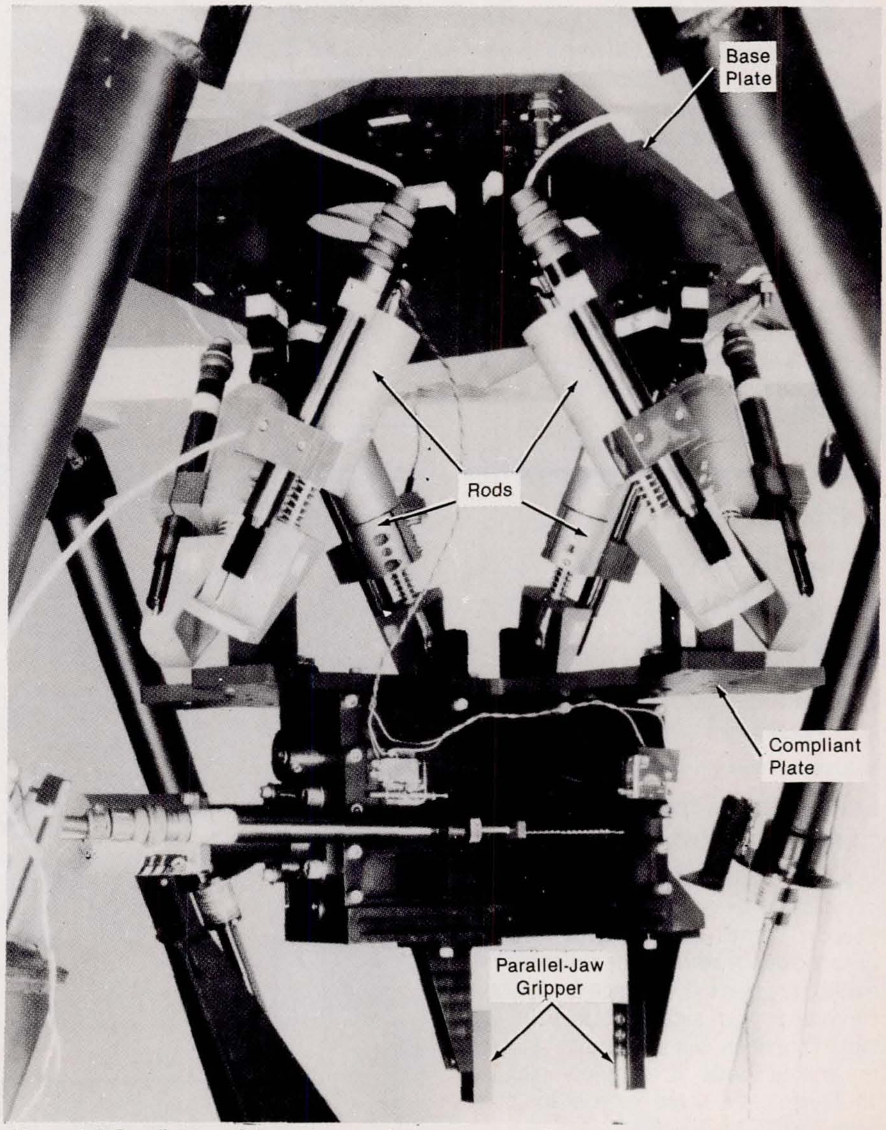


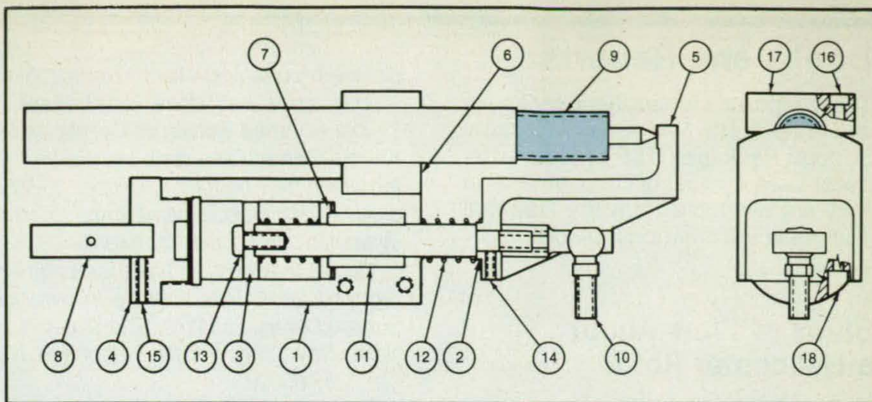
Figure 1. **A Parallel-Jaw Gripper** is mounted on the compliant plate of the compliant-wrist assembly.

sponse to any applied force or torque because the springs in the connecting rods will give, causing changes in the lengths of the rods. A linear displacement transducer measures the change in piston length. The force acting on the rods can be deduced from piston travel if the spring constant is known. It is also possible to use strain gauges to measure the axial forces directly.

The outputs of the transducers are fed to a control computer through a digital-to-analog converter. The computer calculates actual lengths of the rods from these data and uses them to find the position and orientation of the "complaint" plate with respect to the base plate. Since the spring forces act along the rods, their directions are known. From these data the computer finds the vector sums of forces and torques exerted on the "complaint" plate by the rods. Given that the orientation and spatial distribution of the mass of the "complaint" plate and its associated hardware are known, the gravitational components of the forces and torques can be subtracted to yield only the contact forces and torques. If the wrist were to be used in space, this correction for the gravitational field would not be needed.

In the prototype version, the wrist mechanism can exert a force of about 50 lb (220 N) in any direction and can deflect about 0.375 in. (9.5 mm). The rod lengths, spring stiffnesses, and type of displacement sensor can be changed to suit different applications.

*This work was done by Lloyd R. Purves, Franklin Strempek, and Timothy Premack of* **Goddard Space Flight Center**. *For further information, Circle 111 on the TSP Request Card GSC-12868*




| Item | Number of Pieces Required | Description | Material |
|---|---|---|---|
| 18 | 2 | Screw, 8-32 UNC-2A × 1.750 in. Long | Corrosion-Resistant Stainless Steel |
| 17 | 1 | Clamping Block, Linear Variable-Differential Transducer | |
| 16 | 2 | S.H.C.S. .164-32 UNC-3A 0.875 in. Long | Corrosion-Resistant Stainless Steel |
| 15 | 2 | SET SCREW .190-24 UNC-3A 0.375 in. Long | Corrosion-Resistant Stainless Steel |
| 14 | 1 | SET SCREW .164-32 UNC-3A 0.375 in. Long | Corrosion-Resistant Stainless Steel |
| 13 | 1 | SCREW .250-28 UNF-2A 0.500 in. Long | Corrosion-Resistant Stainless Steel |
| 12 | 2 | Spring, Compression | |
| 11 | 1 | Adjustable Ball Bushing | |
| 10 | 1 | Ball-Joint Rod End, With Stud | |
| 9 | 1 | Gauging Linear Variable-Differential Transducer | |
| 8 | 1 | Universal Joint, Bored | |
| 7 | 1 | Spring Retainer, Inner | |
| 6 | 1 | Block, Linear Variable-Differential Transducer | |
| 5 | 1 | Flange | |
| 4 | 1 | Plug | |
| 3 | 1 | Spring Retainer | |
| 2 | 1 | Piston Rod | |
| 1 | 1 | Piston Housing | |

Figure 2. This **Simplified Assembly Drawing** shows the parts of each of the six identical pistons.

# Plug Would Collimate X Rays

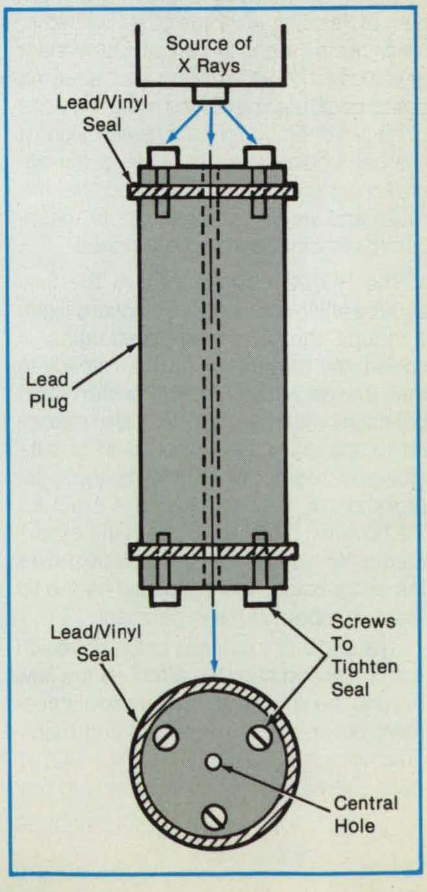
## A simple device would create a narrow, well-defined beam for radiographic measurements of thickness.

*Marshall Space Flight Center, Alabama*

A proposed cylindrical plug would collimate and align x rays with respect to through holes in parts. The plug would help in the determination of wall thickness by radiography.

The plug would contain an axial hole through which the x rays pass from a source through the part (see figure). Composed of lead with lead/vinyl seals at both ends, the plug would be inserted in the through hole. Rays that deviate from the axial direction of the hole 0.050 in. (1.27 mm) in diameter, would be stopped by the lead. The small diameter of the hole would constrict the x-ray beam. Thus, the x rays emerging from the hole would form a sharply defined beam of round cross section, even if the x-ray source is slightly misaligned.

*This work was done by Jeffrey E. Anders and James F. Adams of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*
*MFS-29343*




**Lead Would Absorb X Rays** that do not pass axially through the central hole. Lead/vinyl seals would prevent off-axis rays from passing along the periphery of the plug.

## Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

### Study of Flow About a Helicopter Rotor

A noninvasive instrument verifies a computer program that predicts velocities.

Laser velocimeter measurements confirm predictions of the transonic flow field around the tip of a helicopter-rotor blade, according to a report. The report discusses the measurements, which yielded high-resolution orthogonal velocity components of the flow field at rotor-tip Mach numbers from 0.85 to 0.95, and the use of the measurements in verifying the ability of the computer program ROT22 to predict the transonic flow field, including the occurrences, strengths, and locations of shock waves that cause high drag and noise.

A fringe-mode, forward-scatter laser velocimeter system using the 4,880- and 5145-Å lines of an argon ion laser was designed for the measurements. Because the velocimeter looks along the rotor blade toward the hub as the tip of the blade sweeps by, one spectral line can be used to measure the induced chordwise component of velocity, while the other is used to measure the induced vertical component of velocity. The transmitting and receiving optics could also be moved along the walls of the test chamber to obtain a view along a line perpendicular to the edge of the approaching or retreating blade so that the radial and vertical components of the induced velocity could be determined.

The ROT22 code calculates the flow about a lifting rotor blade in forward flight. Although the full-potential equation is solved, the formulation is quasi-steady in that the derivatives of the perturbation potentials with respect to time are neglected to speed up the computation greatly. However, regardless of the simplifying approximation, the computation is exact for the hovering flight simulated in the experiments. With the code, the flow field over the entire blade was calculated for the tip Mach numbers of the experiment.

The angle of incidence in the tip region was small and had little effect on the flow beyond the tip. Therefore the good agreement between the calculated and measured velocities indicates that the ROT22 code can be used with confidence to predict the important flow field in the tip region.

*This work was done by Michael E. Tauber of* **Ames Research Center** *and F. Kevin Owen of Complere, Inc. Further information may be found in Paper 85-1558 of AIAA 18th Fluid Dynamics and Plasmadynamics and Lasers Conference.*

*Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 18]. Refer to ARC-11790.*

### Vibration-Testing Facility for Aircraft

Equipment, methods, and experience are described.

A report describes equipment and techniques used in the vibration testing of aircraft on the ground at the Dryden Flight Research Facility. It includes discussions of the role of ground vibration testing in the

qualification of new and modified aircraft for flight and of the experience gained from various applications.

Ground vibration tests are performed to identify structural vibrational modes and the associated natural frequencies and dampings. Data from such tests are correlated with the predictions of finite-element mathematical models of the aircraft dynamics. Data from ground vibration tests performed before and after modifications of research vehicles can be compared to assess the significance of those modifications. Vibration-test data can also help to resolve anomalies observed in flight.

A ground vibration test may involve a complete airplane mounted on soft supports like air bags to permit free vibrations, a complete airplane resting on its landing gear, specific parts on a complete airplane, or single components of an airplane tested in isolation. A test is conducted by the sine-dwell excitation method, the single- or multiple-input random-excitation method, or the impact-excitation method; some equipment is unique to each method, while some is common to all. For example, electrodynamic shakers with force ratings of 10, 50, and 150 lb (45, 222, and 667 N, respectively) are used in all methods except impact excitation.

In the sine-dwell method, two or more shakers excite the vibrations in the airplane as the frequency is swept through the range of interest. The vibrational response as a function of frequency is measured by accelerometers at several locations. After the initial frequency sweeps, each vibrational mode of interest is analyzed in detail by measurement of coincident and quadrature components of force and acceleration. Once a mode is thus finely tuned, a modal survey is performed by roving accelerometers.

In the random-excitation method, the shakers are driven by a random forcing function of bandwidth and amplitude specified by the user. Vibrational-response data from accelerometers are processed by a structural-analysis minicomputer system to obtain transfer and coherence functions with sufficient bandwidth to include the vibrational modes of interest. Once data are acquired for the entire airplane, modal parameters are found from calculations in the time domain.

The impact-excitation method is used primarily to test components. The specimen is struck by an instrumented hammer. The decaying vibrational-response signal is multiplied by an exponential window function to reduce leakage. The data are analyzed in the same manner as in the random-excitation method.

Each combination of equipment and technique has its advantages and disadvantages, and none is relied upon solely for all testing. Examples of tests that have been performed include the following:

- Sine-dwell tests of the highly maneuverable aircraft technology (HiMAT) airplane,
- Sine-dwell tests of the flaperon system of the X-29A forward-swept-wing airplane,
- Sine-dwell and random tests of the Jet Star laminar-flow-control airplane,
- Impact tests of a landing-gear door of the rotor systems research aircraft (RSRA), and
- Impact tests of an aileron of the F-15 supersonic airplane.

*This work was done by Michael W. Kehoe of* **Ames Research Center**. *Further information may be found in NASA TM-88272 [N87-27655/NSP], "Aircraft Ground Vibration Testing at NASA Ames-Dryden Flight Research Facility."*

*Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center* *[see page 18].* *Refer to ARC-12141.*

# Machinery



## Fiber-Optic Sensor Would Detect Movements of Shaft

Magnetic inserts are not required.

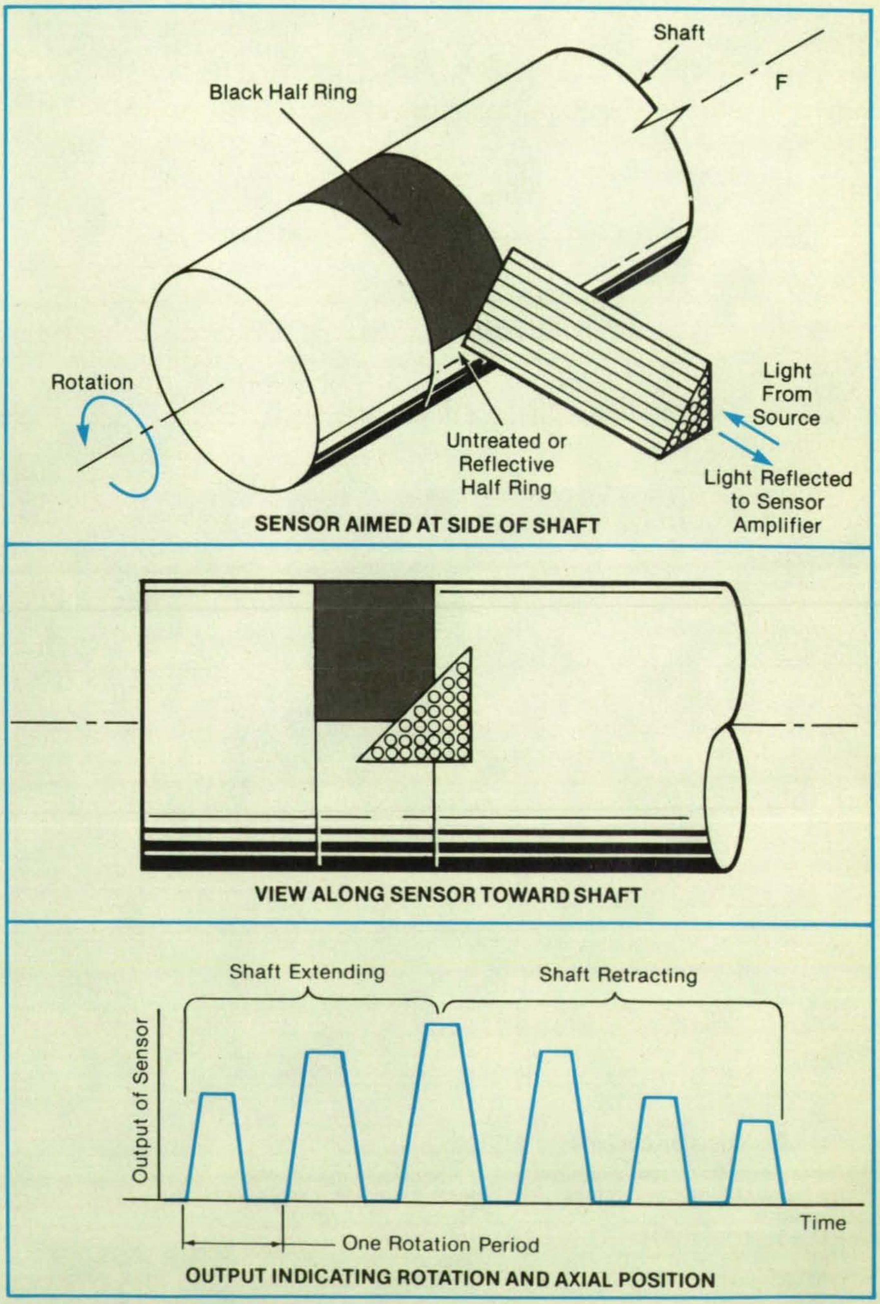
*Marshall Space Flight Center, Alabama*

A proposed fiber-optic sensor would sense both the rotational speed and the axial displacement of the shaft in a motor, pump, or other rotating machine. Unlike magnetic proximity sensors, this sensor does not require magnetic materials, notches, or grooves in the shaft. The only required modification of the shaft is etching or plating the surface (for example, with a black, microscopically rough coat of chromium) to make a ring that is black around half its circumference and reflective around the other half along a short length at one end or some other convenient location.

The fiber-optic sensor would include a bundle containing both light-sending and light-receiving fibers. At the probe end, the bundle would be formed into a triangular cross section, throughout which the sending and receiving fibers would be mixed evenly. The probe would be placed near the shaft, aimed perpendicularly to the axis of rotation, and positioned axially so that part of the black/reflective ring comes within the triangular field of illumination and view of the sensor (see figure).

With this arrangement, the amount of light returned from the probe and, therefore, the output signal of the sensor would vary with time as the black and reflective parts of the ring rotate past the probe. The rotational speed would thus equal the fundamental frequency of the probe-output pulses. Because the fraction of the triangle crossed by the black and reflective areas would vary with the axial position of the shaft, the amount of light and, therefore, the amplitude of the pulses would vary proportionally. Thus, the amplitude of the pulses could be used to infer the axial position of the shaft during operation.

*This work was done by Edmund J. Roschak of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*
*MFS-29382*




A **Triangular Bundle of Sending and Receiving Optical Fibers** would be aimed at a black/reflective ring on a shaft. The frequency and the amplitude of the output pulses of the fiber-optic probe would indicate the rotational frequency and the axial position of the shaft, respectively.

# Tethered Remote Manipulator

Potential advantages include safety and long reach.

*Marshall Space Flight Center, Alabama*

A remote-manipulator concept proposed for the retrieval or inspection of objects in outer space could also be applied underwater or in tanks of hazardous chemicals. Called a "self-propelled line tether" or "space snake" by its inventor, the manipulator is intended for use in places beyond the reach of a jointed rigid-arm manipulator and where it is unsafe or impractical to send humans.

The system would include a tether head on the outer end of a tether cable wound on a motor-driven takeup reel. The head would include a mounting plate with four canted thrustors (i.e., nozzles) facing rearward, a solid-state camera with patterned sources of light facing forward, and a pneumatic inflatable end effector. The head could also include a device to cut the head loose in an emergency.

The tether cable would consist of a tubular outer section that encloses wires carrying power, control signals, camera signals, and the like between the tether head and the operator's control station. A video display at the control station would show the operator what the camera "sees." With this display as a guide, the operator would use a three-degree-of-freedom joystick to control the orientation and direction of forward motion of the head. This control action would produce the desired pitching, turning, or forward motions by selectively firing various combinations of the four thrustors.

The operator would use the reflected patterns from the sources of light as seen by the camera to maneuver the head into the final position to inspect or grasp the object. To grasp the object, the operator would inflate the remote manipulator. The object would then be retrieved by winding the cable onto the takeup reel. So that the operator could continue to control the motion of the head during retraction of the cable, the maximum takeup force of the reel would be less than the resultant thrust of the four thrustors.

The concept could be modified in any number of ways to suit specific situations. For example, the underwater version would be made neutrally buoyant and would be propelled by pressurized water instead of pressurized gas. The pressurized gas or pressurized water in the outer-space or underwater version, respectively, could be transported from the reel station to the head by a hose inside or alongside the tether cable. Alternatively, water could be pressurized by an electrically powered pump in the head of the underwater version, and the supply of gas could be mounted in the head of an outer-space version intended for brief use. Other options might include sensors to measure angles, forces, accelerations, positions, and distances; latches instead of or in addition to the powered remote manipulator; and additional thrustors for rolling and lateral translation.

*This work was done by Thomas C. Bryan of* **Marshall Space Flight Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 18]. Refer to MFS-28305.*

# Two-Thumbed Robot Hand

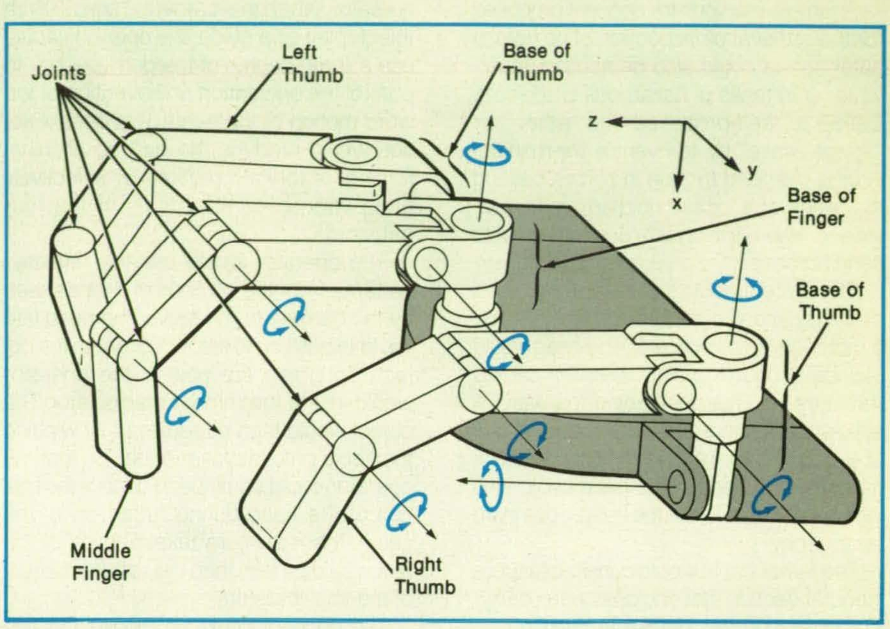
## A middle finger and two thumbs would grasp and sense the shapes of a variety of objects.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed robot hand would include thumblike members on its left and right sides and a fingerlike member at its middle. This configuration of digits would enable the hand to adapt to variously shaped objects, to grasp them robustly and reliably, and to manipulate them. It would also reduce the complexity of the control mechanisms and provide kinesthetic perception of the shapes of grasped objects.

Each thumb would have three rotational axes at its base joints and one rotational axis at each of its two other joints (see figure). The middle finger would have two rotational axes at its base joints and one rotational axis at each of its two other joints.

A dc-motor-and-gear assembly would rotate the thumb about the *z*-axis base joint to switch the whole thumb between upward-facing and downward-facing positions (this motion would not be provided for the middle finger). Another dc-motor-and-gear assembly would rotate the thumb or the center finger about the *x*-axis base joint, enabling adjustment of the yaw angle




The **Mechanical Hand** with two thumbs and a middle finger could be made from commercially available components. With specially designed dc motors and assemblies of gears, the size of the hand could be reduced considerably.

of the thumb or finger. A dc-motor-and-tendon connection would rotate a thumb or the middle finger about the y-axis base and other joints to control pitch angles and bending. Overall, the hand would have 14 joints controlled by eight motors: three motors for the yaw angles of the three members, two for the roll angles of the two thumbs, and three for bending the three members.

In a limited sense, the new hand could be considered anthropomorphic. It could be configured as part of a simulated human right or left hand or as overlapping parts of left and right hands. It could perform a wide range of grasping and manipulating motions. Moreover, the two thumbs would give the hand a mechanical symmetry and balance well suited to handling objects in industrial tasks.

*This work was done by Sukhan Lee of the University of Southern California for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 96 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17274.*

## Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

### Injected Water Augments Cooling in Turboshaft Engine

Additional cooling enables operation at higher than usual power.

A report describes experiments in which water was injected into the compressor-bleed cooling air of an aircraft turboshaft engine. The injection of water had previously been suggested as a way to provide the additional cooling needed to sustain operation at power levels higher than usual. Such operation involves turbine-inlet temperatures high enough to shorten the lives of the first-stage high-pressure turbine blades. The latent heat of vaporization of the injected water serves as an additional heat sink to maintain the blades at their design operating temperatures during high-power operation.

The engine was modified by addition of the water-injecting apparatus to the cooling-air accelerator, and the usual complement of instrumentation was retained. Additional instrumentation was installed to measure the pressures of the cooling air upstream and downstream of the cooling-air accelerator. Thermocouples were added to measure the temperatures of the inflowing water and of the steam/air mixture upstream and downstream of the accelerator. An optical pyrometer measured the temperatures of the leading edges of the first-stage turbine blades.

By itself, the injection of water both lowered the temperatures of the blades and caused the engine to run slower. This result was anticipated because the cooling air becomes denser as water is added; and as more compressor air is diverted for cooling, less is available to drive the turbine. Furthermore, the cooling shortens the turbine blades by thermal contraction, causing an increase in the clearance of the tips of the blades and a consequent decrease in efficiency.

In another test, the cooling water was turned on and the flow of fuel then increased until the engine reached the normal operating speed for dry cooling. In this condition, the temperature at the leading edges of the blades was near the normal value, but the output power was higher than it was without water. The increase in power was about 3.5 percent for a water/cooling-air flow ratio of 6 to 7 percent, and the corresponding increase in the inlet temperature was 60 °F (33 °C).

The injection of water at flow ratios beyond 7 percent did not provide an additional decrease in the temperature of the leading edges of the blades, apparently on account of peculiarities of the apparatus. Concern for other unprotected components in the hot section of the engine prohibited tests at higher powers. However, projections from design studies and the tests thus far indicate that if these limitations can be overcome and the inlet temperature raised by 300 °F (167 °C), then the power could be increased by 17 percent without affecting the normal blade temperature.

*This work was done by Thomas J. Biesiadny of* **Lewis Research Center** *and Brett Berger, Gary A. Klann and David A. Clark of the U.S. Army Aviation Research and Technology Activity. Further information may be found in NASA TM-89817 [N87-20280], "Contingency Power for Small Turboshaft Engines Using Water Injection into Turbine Cooling Air."*

*Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.*
*LEW-14706*

# Fabrication Technology



## Three-Dimensional Coaxial Weld Monitoring

Parallax would be incorporated into the optical system.

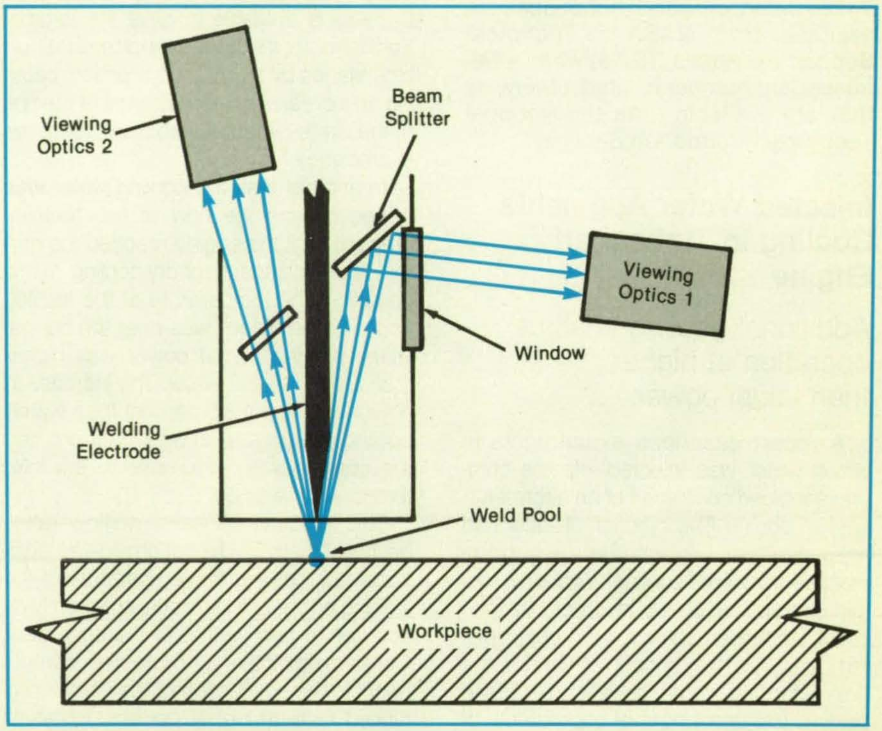
*Marshall Space Flight Center, Alabama*

A proposed optical system for a coaxial-viewing welding torch would enable the perception or measurement of depth — that is, of position along the axis of the torch. At present, such optical systems give only two-dimensional views of the welding areas: operators must rely on shadows or changes in focus to infer differences in depth.

In the proposed system, light from the welding area would be passed through a beam splitter into two optical trains to form two images, each being the view along a line that makes a small angle with the axis of the torch (see figure). The two lines of sight would intersect at the weld pool. The parallax between the two views would provide the sensation of depth over the entire field of view.

Information on depth could be used to evaluate the height of the surface of the seam (to detect mismatches, burrs, and the heights of flanged joints), the convexity or concavity of the weld bead (which relates to the penetration of the weld and the rate of deposition of filler metal), and oscillations of the weld pool (which relate to penetration). The information on depth is also useful for determining the angle of entry of the filler wire with respect to the surface of the workpiece and the distance of the torch from the workpiece. The two images might be processed electronically to extract and/or interpret the data on depth.

*This work was done by Stephen S. Gordon of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*
*MFS-29373*




The **Parallax Between Two Sets of Viewing Optics** would provide information on depth in the field of view.

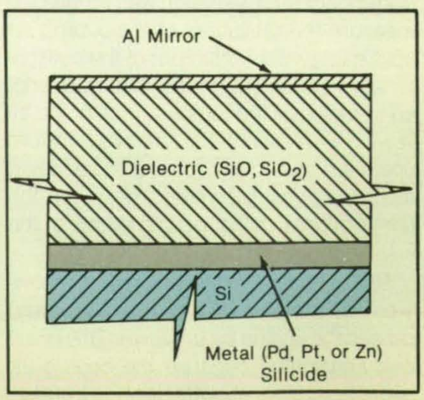
## Improved Method for Making Infrared Imagers

Properties of a thin dielectric layer are adjusted precisely.

*Goddard Space Flight Center, Greenbelt, Maryland*

A deposition technique has been found to improve the fabrication of infrared imaging devices. The technique is applied to a dielectric layer of SiO and $SiO_2$ (see figure), which is critical to the operation of a device. For an imager to work properly, thickness of the dielectric layer has to be adjusted precisely in coordination with its absorption coefficient and the wavelength of the light to be imaged.

The absorption coefficient and index of refraction are adjusted by altering the composition, $SiO_x$. The dielectrics used previously — electron-beam-evaporated $SiO_x$ or chemical-vapor-deposited $SiO_2$ — produce satisfactory layers but have several disadvantages. The stoichiometry of the $SiO_x$ (and, therefore, the index of refraction and the absorption coefficient) are variable and difficult to control in the electron-beam process. Chemical-vapor deposition pro-




The **New Deposition Process** enables the adjustment of the thickness and index of refraction of the critical dielectric layer to within ±1 percent.

duces a dielectric layer of controllable index of refraction, but the high temperature of this process degrades the underlying metal silicide layer during the 30 minutes needed to deposit the dielectric layer. Furthermore, chemical-vapor deposition necessitates the use of a cumbersome lift-off technique during subsequent processing.

In the new technique, a suitable $SiO_2$ dielectric is deposited at room temperature by a magnetically-enhanced glow discharge, using silane and nitrous oxide as precursors. This technique enables the control of the thickness and the index of refraction of the dielectric to within ±1 percent; in comparison, the previous techniques yielded ±10-percent variations.

The $SiO_2$ deposited by the new technique can be wet-etched, and therefore the lift-off step can be eliminated. The net result is higher yield and lower cost, without sacrifice of the performance of the imagers.

*This work was done by G. Kaganowicz, A. G. Moldovan, and J. W. Robinson of David Sarnoff Research Center, for* **Goddard Space Flight Center**. *No further documentation is available.*
*GSC-13135*

## Canning of Powdered Metal for Hot Isostatic Pressing

The quality of the specimen is enhanced by an improved canning process.

*Lewis Research Center, Cleveland, Ohio*

An improved method has been developed for canning specimens for hot isostatic pressing. The specimen is placed inside a refractory-metal ring, which is then sandwiched between two refractory-metal face sheets. This assembly is placed inside a die, which is then positioned in a vacuum hot press. The specimen is heated to a set temperature at a prescribed vacuum to burn off all of the binder in the specimen.

After burning off of the binder, the temperature of the specimen is raised to a higher set temperature. A prescribed pressing load is then applied to the specimen to deform the refractory-metal ring, to bring about a solid-state-diffusion weld between the ring and face sheets, and to densify partially the composite specimen. The size and shape of the specimen are now locked in place, and a perfectly-fitted hot-isostatic-pressing can, sealed at high temperature and high vacuum, has now been formed. The specimen can now be densified completely by hot isostatic pressing.

This procedure offers several advantages over the prior art. The powder-metallurgy composite is totally purged of the binder sealed in the can in a single operation. This procedure prevents outgassing during hot isostatic pressing, which outgassing could cause incomplete densification, interstitial contamination, and embrittlement of the specimen. The perfectly fitting can maintains the size, shape, and uniformity of the specimen and, thereby, prevents warpage of the specimen caused by uneven stresses. Finally, because it is not necessary to electron-beam weld the can, the material in the weld region does not recrystallize, and there is little possibility of cracking.

*This work was done by John J. Juhas of* **Lewis Research Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14719.*

# Plating Patches on Heat-Exchanger Jackets

Permanent repairs are made without welding.

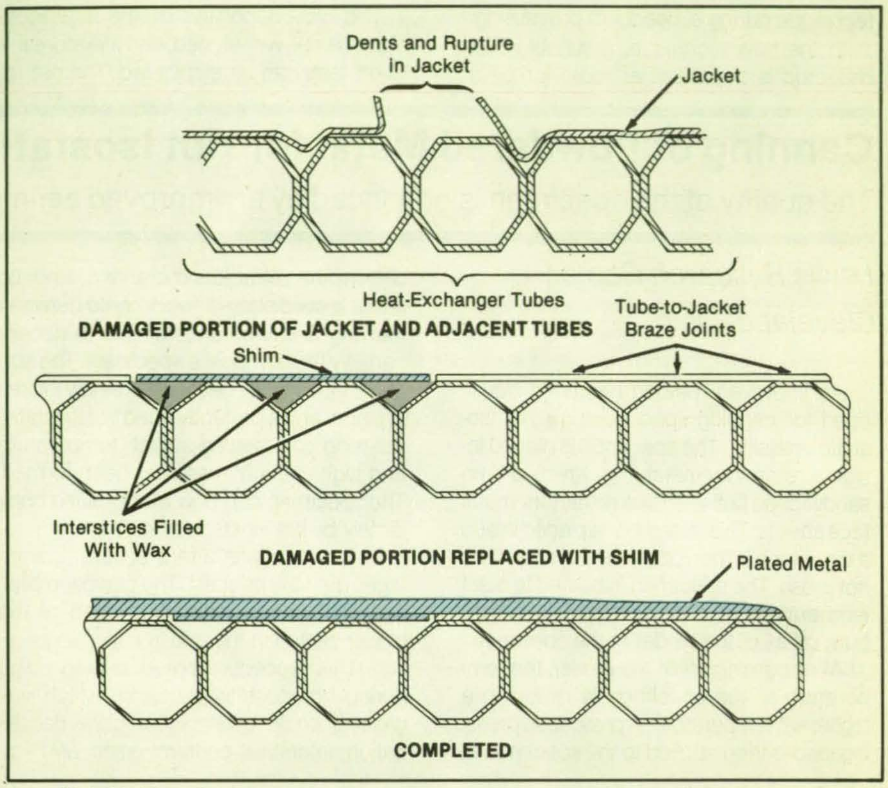
*Marshall Space Flight Center, Alabama*

A technique used to repair the nickel-alloy nozzle jacket of the Space Shuttle main engine (SSME) should also be applicable to other metal heat-exchanger jackets that have similar configurations. The technique does not require welding, brazing, soldering, or other operations that involve high temperatures and consequent damage to surrounding areas.

The portion of the jacket around a damaged area is removed by grinding and polishing out to edges adjacent to tube/jacket braze bonds (see figure). The spaces between tubes are filled with wax to prevent contamination of those spaces during subsequent plating.

A shim having the same thickness as that of the jacket [a nickel alloy 0.10 in. (0.25 mm) thick in the case of the SSME] is cut to replace the removed jacket material. After the shim is put in place, the shim and the adjacent area are plated (with nickel in the case of the SSME) to the required thickness [0.035 in. (0.89 mm) in the case of the SSME] at the center of the patch, tapering to 0.002 in. (0.05 mm) at the edge of the patch. The wax is then removed.

The maximum thickness of the plating in a particular case has to be determined by structural analysis to be sufficient to prevent the patch from buckling. The taper helps to maintain a smooth transition of stresses from the patch to the rest of the jacket. The edge of the patch is formed into a wave pattern to contribute further to a smooth transition of stresses.




**Metal Is Plated** over a shim that replaces the damaged portion of the jacket.

*This work was done by Henry Loureiro and Frank Kubik of Rockwell International Corp. for **Marshall Space Flight Center**. For further information, Circle 1 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 18]. Refer to MFS-29345.*

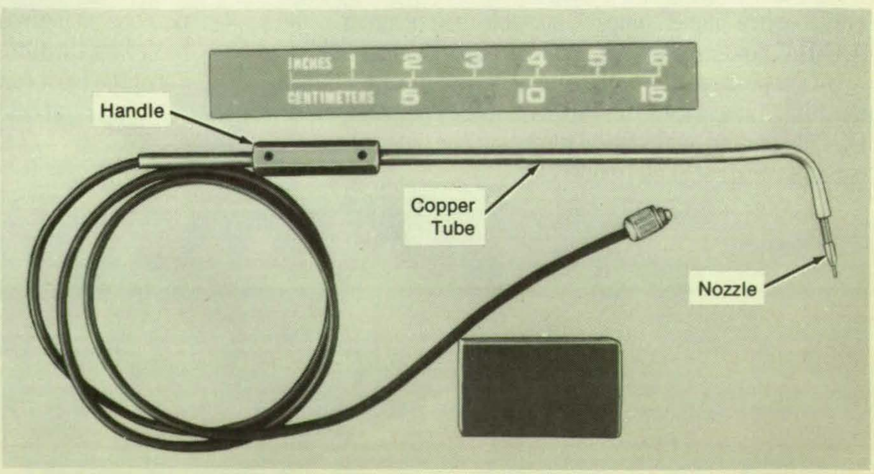
# Bendable Extension for Abrasive-Jet Cleaning

Hard-to-reach places can be cleaned more easily.

*Marshall Space Flight Center, Alabama*

An extension for an abrasive-jet apparatus can be bent to provide controlled abrasive cleaning of walls in deep cavities or other hard-to-reach places. Designed for the controlled removal of penetrant inspection dyes from inside castings, the extension tube can also be used for such general grit-blasting work as the removal of scratches.

A bendable tube (see figure) is installed over a 3/16-in. (4.8-mm) diameter, neoprene extension hose that is part of a commercial abrasive-jet apparatus. Glass beads are pushed through the hose by a blast of air at a pressure of 80 psi (0.55 MPa). A standard carbide abrasive-jet nozzle with an inner diameter of 0.040 in. (1.0 mm) is installed in the hose at its outer end.




A **Bendable Copper Tube** supports a commercial abrasive-jet extension hose. The abrasive jet was used to refinish the surface around the scribe line on the left side of the plate.

The tube, which is made of copper, has a ¼-in. (6.4-mm) outside diameter and is cut to the desired length. A ½-in. (12.7-mm) wide and 2-in. (51-mm) long, hexagonal brass handle is mounted on the tube with two setscrews. The hose is slipped through the tube until the nozzle protrudes at the outer end; then the tube is bent to the desired shape.

*This work was done by Walter Mayer of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 18]. Refer to MFS-29298.*

# Making and Inspecting Large Wire Grids

Old techniques are refined and combined to make new polarizers.

*Goddard Space Flight Center, Greenbelt, Maryland*

Equipment and procedures have been developed for the fabrication and inspection of large, precisely-spaced, flat grids of wire. Such grids are useful primarily as polarizers and beam splitters for electromagnetic radiation in the overlapping ranges of long infrared and microwaves. The new manufacturing technology includes refinements and combinations of established techniques for winding grids of electron tubes and ruling optical gratings and incorporates recent developments in electronic control and laser/electronic-based metrology.

The manufacturing equipment and process are illustrated in the figure. A wire grid is wound on one-half of a frame of Invar 36 (or equivalent) low-thermal-expansion alloy machined and ground by optical techniques to a flatness of 2 μm. The frame is mounted with steel bearing rods at opposite ends and aligned on an aluminum platen so that the wires will wrap in the proper direction. The platen is mounted in a modified milling machine, which turns the platen at 4 r/min to wrap the wire. The wire (typically gold-coated tungsten 20 μm in diameter) is released onto the rotating frame through a constant-tension active despooling system and a glass wire guide.

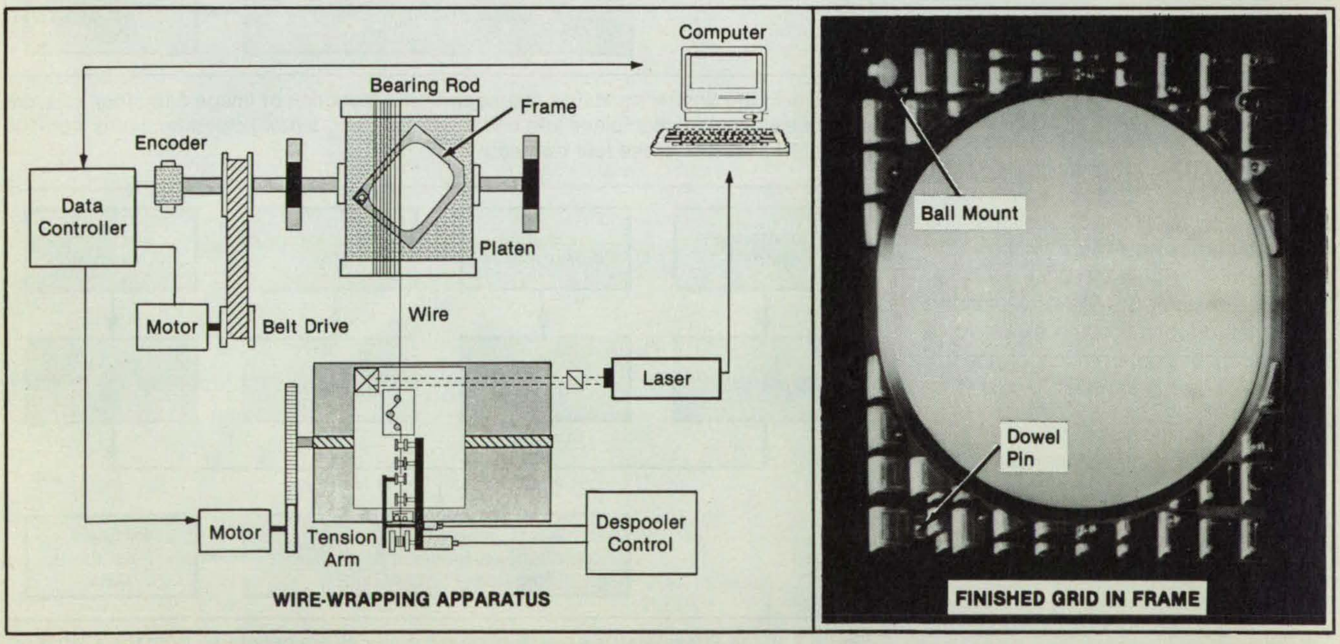
The despooler and guide are mounted on a motor-driven cathetometer that can travel as much as 25 cm with minimal twist. The position of the cathetometer is measured by a laser ranging interferometer operating in conjuction with a desktop computer. During the portion of each revolution of the platen when the frame faces away from the wire guide, the computer commands the cathetometer to translate the despooler and wire guide one grid interval (typically 53 μm) along the edge of the frame.

When the cathetometer has stepped along the entire length of the frame and the entire aperture is wrapped with the wire grid, epoxy is dropped into a groove in the frame to affix the wires. When this epoxy has cured, more epoxy is applied to the portion of the frame outside the groove, and the other half of the frame is clamped on, aligned with dowels. After curing of the epoxy, the portion of the wire protruding from the frame is cut away, and the completed frame and grid are removed from the platen.

The flatness of the grid and the spacing of the wires are measured with equipment similar to that used to wrap the wires. (Some of the same equipment can be used for wrapping and measurement.) For the measurement of flatness, the grid is mounted on a two-axis translation stage on which the y-axis is monitored by the laser ranging interferometer with a straightness-measuring adapter. The grid is translated along the x-axis in front of a fixed microscope with a depth of focus of ~1 μm. At each inspection point, the y-axis translation is adjusted for best focus, and the interferometer reading is sent to the computer. The deviation of the resulting computer-generated plot of y vs. x from a straight line gives a measure of the deviation from flatness.

For the measurement of spacing, the x-axis is monitored by the laser ranging interferometer, and the microscope images the wires on a photodetector, the output of which is sampled by an analog-to-digital converter and transmitted to the computer. The computer locates the edges of the wires by looking for signals above and below a threshold value and uses the locations of the edges to compute the distances between the wires.

*This work was done by Thomas J. Magner, Richard D. Barney, William L. Eichhorn, and Henry P. Sampler of* **Goddard Space Flight Center**. *For further information, Circle 137 on the TSP Request Card.*
*GSC-13117*




**Wire Is Wrapped on a Frame Half** that is translated under automatic control to achieve the desired space between turns. The frame halves are put together, and the excess wire is cut away, leaving the finished grid mounted in the frame.

## Compression of Data in Imaging Radar Polarimetry

The number of data is reduced by a factor of 12.8.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Algorithms have been developed to reduce the number of radar polarimetric data that must be processed to synthesize an image of an arbitrary combination of transmitting and receiving polarizations. Such techniques for the compression of data are needed because a typical synthetic-aperture-radar polarimetric image contains 4,194,304 one-look picture elements (4,096 in azimuth by 1,024 in range) and requires about 128 megabytes of storage capacity. The algorithms bring the image-processing requirements within the computing capabilities of typical users, without degrading the images excessively.

One of the algorithms is based on the scattering matrix, which is a 2-by-2 matrix of complex numbers that specify the amplitude and phase relationships among the horizontally- and vertically-polarized transmitted (or incident) and received (or backscattered) radar signals. The other algorithm is based on the phase matrix, a 4-by-4 matrix of real numbers that specifies the relationship between the transmitted and received Stokes vectors. The Stokes vector **G** is a four-dimensional vector defined by

$$G_0 = a_h^2 + a_v^2,\ G_1 = a_h^2 - a_v^2,\ G_2 = 2a_h a_v \cos(\delta),\ G_3 = 2a_h a_v \sin(\delta)$$

where $a_h$ and $a_v$ are the horizontal and vertical amplitudes, respectively, and $\delta$ is the phase difference between them. Either matrix can be used to construct an image of any combination of polarizations, and both matrices are equivalent as long as the waves are fully polarized ($G_0^2 = G_1^2 + G_2^2 + G_3^2$). However, the Stokes-vector and phase-matrix representation allows for a diffuse (depolarized) component, the importance of which can be measured by $G_0^2 - G_1^2 - G_2^2 - G_3^2$.

In the scattering-matrix approach to the compression of data (see Figure 1), four consecutive picture elements along the azimuth direction are combined into one by constructing an "average" scattering matrix $S_{ij}$ from the scattering matrices $A_{ij}$, $B_{ij}$, $C_{ij}$, and $D_{ij}$ of the four elements. The amplitude of an element of the "average" matrix is given by

$$|S_{ij}| = [A_{ij}A_{ij}^* + B_{ij}B_{ij}^* + C_{ij}C_{ij}^* + D_{ij}D_{ij}^*]^{1/2}$$

while the phase of the element is given by

$$Arg(S_{ij}) = Arg[A_{ij}A_{hh}^* + B_{ij}B_{hh}^* + C_{ij}C_{hh}^* + D_{ij}D_{hh}^*]$$

where the subscript $h$ denotes horizontal polarization, either of the subscripts $i$ and $j$ can denote horizontal or vertical polarization, and the phase of $S_{hh}$ is arbitrarily set at zero. The calculation of the phase in this method puts more weight on vectors of large amplitude, which are presumably less vulnerable to noise.

The information to be coded for the "average" picture element consists of four amplitudes and can be stored in 8 bytes: 2 bytes for the maximum amplitude expressed as a mantissa and an exponent, 3 bytes for the remaining amplitudes, and 3 bytes for the phases. Thus, the data have been reduced to 1,024-by-1,024 picture elements of 8 bytes apiece, representing an overall reduction by a factor of 16.

In the phase-matrix approach (see Figure 2), four consecutive picture elements in the azimuth direction are combined into one by simple addition of their phase matrices: this is equivalent to four-look averag-

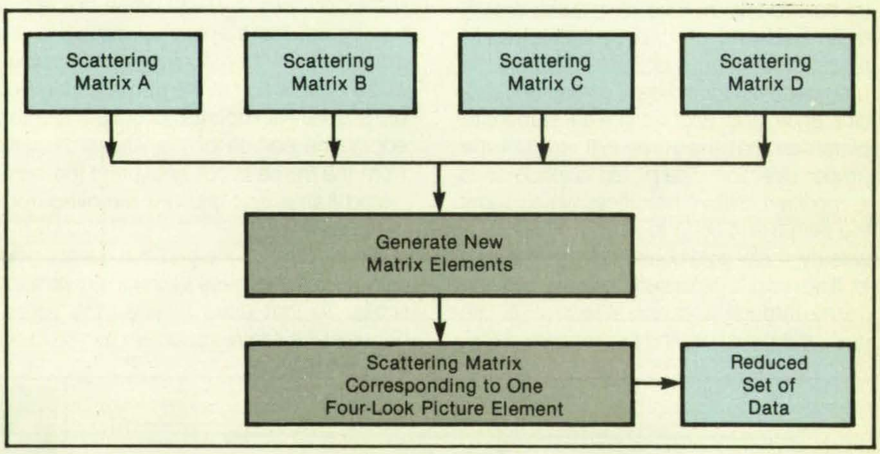



Figure 1. In the **Scattering-Matrix Approach** to the reduction of image data, four adjacent picture elements are combined into one by synthesizing a new scattering matrix from the scattering matrices of the four elements.

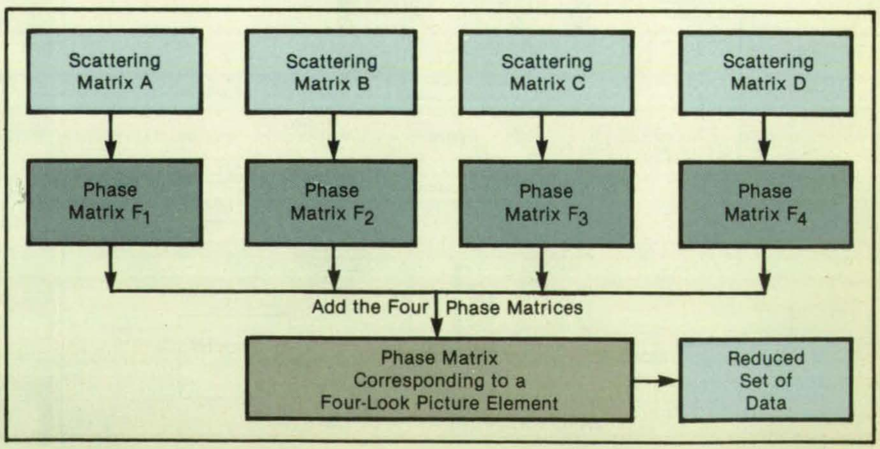



Figure 2. In the **Phase-Matrix Approach**, phase matrices are generated from the scattering matrices of four adjacent picture elements, and the four phase matrices are added to combine the four picture elements into one.

ing. In this case, the complete phase matrix of an "average" picture element can be stored in 10 bytes, and the resulting image of 1,024-by-1,024 elements can be stored in 10-by-1,024-by-1,024 bytes, representing an overall reduction by a factor of 12.8.

The performances of the two approaches were measured in terms of the errors between original polarization data from representative terrain and the polarization signatures synthesized from the reduced sets of data. The scattering-matrix approach was found to yield errors approaching $10^{-2}$, while the phase-matrix approach typically yielded errors less than $10^{-3}$.

*This work was done by H. A. Zebker, D. N. Held, J. J. Van Zyl, P. DuBois, and L. Norikane of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 37 on the TSP Request Card.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17184.*



## Paradigm for Statistical Analysis of Threshold Detection

Relative values are assigned to double mistakes and changed iteratively.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A method for the statistical analysis of threshold detection saves experimental time by enabling the use of the same set of measurements with respect to two thresholds. The method accounts for double mistakes, which are unresolvable by the threshold-detection technique used heretofore.

The method is best explained by the example of an x-ray reading test in which a subject is asked to decide whether a spot target is darker or larger than a reference spot. Data are to be taken with the target either darker or larger than (but never both and never equal to) the reference spot. The data are used to construct two receiver operating characteristic (ROC) curves, one for the detection of darkness differences and one for the detection of size differences.

The problem is how to evaluate data points at which the subject says "larger" when the target is darker, or vice versa. Does such a point represent a miss for the darker case and/or a false positive for the larger case, or vice versa? In the conventional method, one avoids the problem by taking two sets of data, one with the target darker and one with the target larger.

In the new method, the two ROC curves are constructed from the same set of data, which includes both the darker and the larger cases. Instead of attempting to distinguish between misses and false positives, one treats such double mistakes by assigning a probability to each component mistake, and the probabilities add up to 1. Thus, both mistakes are weighted and counted probabilistically, and, in effect, one sidesteps the problem of double counting of data points.

The weights are assigned relative to the parameters of each double mistake, and the ROC curves are computed iteratively. Once the first ROC curve is computed, the values of the independent variables (darkness and size) are anchored from the curve, and new weights are assigned to the component mistakes, subject to the requirement that they add up to 1. A new ROC curve is computed, and so on until the ROC curves converge.

*This work was done by Daniel B. Diner of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 106 on the TSP Request Card.*
*NPO-17529*

## Functional Microspheres

Tiny beads develop from an aqueous solution.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A new process forms beads of polyglutaraldehyde directly from a solution. Thus far, beads ("microspheres") of 0.5-to-1.0-micron diameter with fluorescent or magnetic properties have been made. They are useful in biology, clinical chemistry, and biochemistry since they readily attach to red blood cells when combined with suitable antibodies. The fluorescent or magnetic properties allow such marked cells to be traced and identified.

Previously, glutaraldehyde was polymerized in an aqueous solution. In the new process, a surfactant is added to the aqueous solution, and microspheres are formed. The diameters are uniform and controllable, depending on the glutaraldehyde concentration, the emulsifier concentration, and the pH (see figure).

In this process, a solution of 5 percent glutaraldehyde and 1 percent selected surfactant is polymerized in a mechanical shaker for several hours at pH 11.0 and room temperature. The beads thus formed are washed and collected.

To make fluorescent microspheres, 1 mg of fluorescein isothiocyanate is reacted with ethylene diamine. The product is added to the solution in the shaker. For magnetic microspheres, 2 percent ferrofluidic solution is added to the aqueous solution in the shaker. The magnetic beads are separated from the other reaction products by a magnet.

*This work was done by Alan Rembaum and Shlomo Margel of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 79 on the TSP Request Card.*

*Title to this invention, covered by U.S. Patent No. 4,267,235, has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)]. Inquiries concerning licenses for its commercial development should be addressed to*

*Edward Ansell*
*Director of Patents and Licensing*
*Mail Stop 301-6*
*California Institute of Technology*
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*Pasadena, CA 91125*

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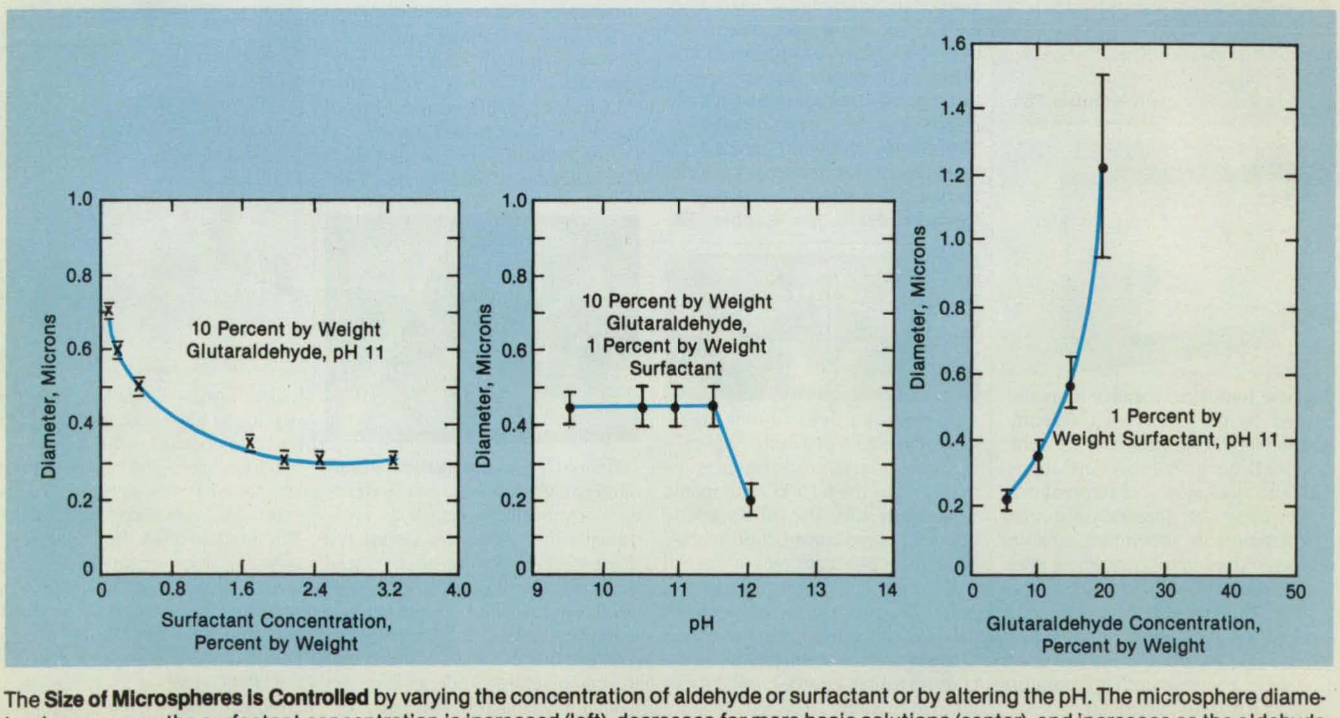
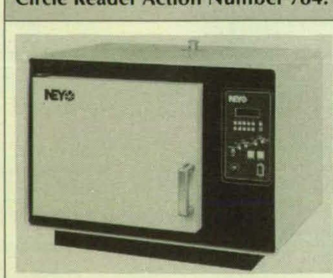



The **Size of Microspheres Is Controlled** by varying the concentration of aldehyde or surfactant or by altering the pH. The microsphere diameter decreases as the surfactant concentration is increased (left), decreases for more basic solutions (center), and increases as the aldehyde concentration is increased (right).

# New on the Market

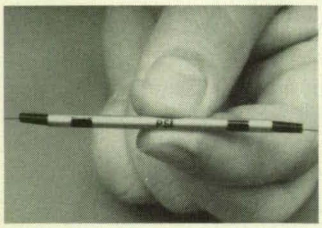
A portable, battery-powered **sound intensity meter** from Caldon Inc., Pittsburgh, PA, pinpoints sound sources and measures sound levels, even in the presence of background noise in factories. Sound intensity can be measured over the 50 Hz to 4 KHz range and displayed continuously in real time on an analog meter that shows both magnitude and direction. Called SIM 2000, the meter consists of an electronic unit containing the computing circuits and display, and a probe with twin microphones and preamplifiers. Applications include quality control, trouble shooting, field inspection, predictive maintenance, and noise reduction.
**Circle Reader Action Number 794.**

Togai InfraLogic's new **Fuzzy-C Compiler** lets software developers apply the benefits of artificial intelligence to real-time "decision-based" commercial applications such as imaging systems and stock trading expert systems. Developers can use the compiler to integrate knowledge bases directly into applications written in C, or to create entirely new applications. The Fuzzy-C Compiler features a knowledge representation syntax that allows users to create "fuzzy logic" production rules and membership graphs, an inference engine which can be configured for specific solutions, and a debugger for rapid rule development.
**Circle Reader Action Number 784.**

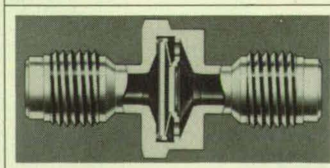



A new **benchtop furnace** manufactured by the J.M. Ney Company, Bloomfield, CT, features a 2.2 cubic meter heating chamber with adjustable air flow rates and automatic air circulation. An integrally-mounted programmable controller enables programming of two ramp/heat rates, temperature levels, and hold/soak times. The Model 2-1350A furnace is suited for ash determinations, heat treating, thermal cycling, coal analysis, and many other laboratory test and quality control functions.
**Circle Reader Action Number 788.**

A new **software program** from the Electronic Signature Lock Corp., Fall Creek, OR, **improves the security of computer systems and networks** by denying access to unauthorized users—even when proper passwords are entered. It assigns users electronic signatures based upon their unique keystroke dynamics and typing patterns. Since patterns can vary with the same user, the software employs a statistical filtering routine for analyzing patterns and determining the probability of proper identity. The chances of the program granting unauthorized access are less than one in a million, according to the manufacturer, even when the unauthorized person knows the correct code or password. Compatible with all popular operating systems, the program runs on microcomputers, minis, mainframes, LANs, and networks.
**Circle Reader Action Number 792.**



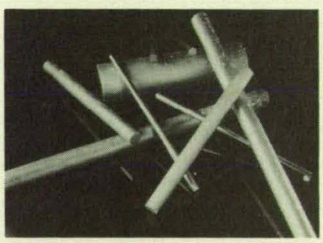

A quick and easy method of mechanically **splicing fiber optic cable** has been invented by PSI Telecommunications Inc., Burbank, CA. Compatible with any single or multi-mode fiber, the Lightlinker™ Splice System includes a patented glass alignment guide that automatically aligns fiber ends for consistent splice losses of less than .1dB. Fiber end preparation is achieved using a scribe and cleave tool that prepares both fiber ends and negates the need for end polishing. The splicing procedure typically requires seven minutes to complete, including a five minute curing time.
**Circle Reader Action Number 778.**



A new **check valve** featuring an all-welded design that ensures safe containment of system fluid has been introduced by the NUPRO Company, Willoughby, OH. The valve's unique bonded poppet construction enables accurate, repeatable crack and reseal performance. Cracking pressure is nominally two psi or less and the valve reseals without back pressure. Made of stainless steel, the valve contains no rubbing parts, lubricants, or internal threads.
**Circle Reader Action Number 798.**

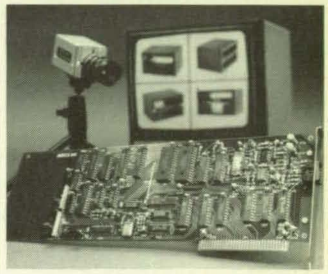

Union Carbide's Advanced Ceramics Division has introduced a **boron nitride aerosol spray** for such applications as high-temperature mold release, anti-corrosion coating, and machinery lubrication. In addition, the spray is effective as an anti-stick agent for materials processed at high temperatures. Composed of hexagonal crystals of boron nitride in a solvent base, the coating exhibits a high level of electrical resistivity and a low coefficient of friction. Each 16-ounce can provides about 100 square feet of coverage.
**Circle Reader Action Number 800.**


**The BUG™ Voice Command System** from Command Corp. Inc., Norcross, GA, enables CAD workstation users to say commands instead of typing them or using other manual input methods. The BUG system performs speech recognition continuously and in real time. It features a starter lexicon of commands for popular CAD software and includes a 25 MHz microcomputer on an expansion card that fits any 8- or 16-bit slot in an IBM PC, AT, '286, or '386 compatible.
**Circle Reader Action Number 786.**

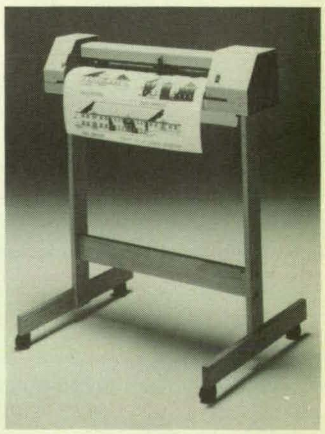


Terfenol-D, a **magnetostrictive alloy** offering high strain and energy density, is now available from Edge Technologies Inc., Ames, IA. Useful as a drive element for transducers and actuators, the alloy features microsecond response time, with strains five to ten times greater than exhibited by piezoelectric ceramics, according to the manufacturer. Terfenol-D comes in a variety of shapes and sizes.
**Circle Reader Action Number 796.**

Eastman Kodak Company scientists have developed an ultra-high resolution **electronic image sensor** with four million picture elements (pixels)—more than double the resolving power of current commercial sensors. The pixels, each a tiny square measuring 9x9 microns, sense impinging light, which is converted into electrons and processed by the device to produce a video signal representing the image. The new sensor has a photoactive area five times larger than Kodak's 1.4 megapixel sensor, the world's first million-pixel image sensor, introduced in 1986.
**Circle Reader Action Number 790.**



BEECO Inc., Indianapolis, IN, has introduced the FG-B100, a **single-board frame grabber** that adds real-time acquisition and display capabilities to IBM PC/XT/AT and compatible computers. The FG-B100 instantly digitizes, stores, and accesses images while providing continuous display of image memory. Applications include image archiving, thermal imaging, surveillance, and x-ray inspection. The frame grabber retails for $895, including manual and demo/utility software.
**Circle Reader Action Number 782.**

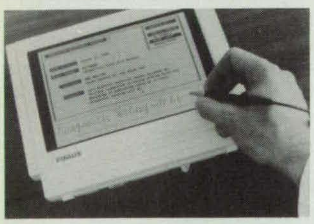


Ioline Corp., Kirkland, WA, has developed a low-cost "**personal plotter**" that operates without a conventional keyboard. Instead, parameters are plotted using a screen on the host computer, known as the host keypad. This function offers the convenience of having all values appear on a single screen. Designated the LP3500, the single-pen plotter accepts media sizes A-D and emulates the HP-GL and DM/PL languages. Listed at $3,195, the LP3500 plots at 10 inches per second with .001-inch repeatability.
**Circle Reader Action Number 780.**

# New on the Market

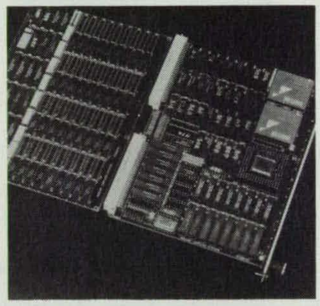

Watlow Electric, St. Louis, MO, is offering a **free demonstration disk** to introduce the Series 985 vertical 1/8 DIN temperature controller. The disk allows users to image the control face, set operating parameters, and judge performance of the Series 985, a microprocessor-based controller featuring dual digital displays, a wide range of inputs and outputs, and both auto and manual modes with bumpless transfer. The free disk requires an IBM PC/XT/AT or compatible computer, EGA or VGA display, and a single 5¼ inch disk drive.
**Circle Reader Action Number 764.**

M1, an all-purpose **lubricant/protectant** from the Starrett Consumer Products Division, Charleston, SC, features a fast-drying agent designed to prevent dust, dirt, and film build-up. The lubricant works quickly to free frozen nuts, bolts, and metal parts without silicone, and stops rust by forming a molecular shield that bonds to the metal. The nonsoluble product gets beneath moisture to lift it away from the surface being protected.
**Circle Reader Action Number 768.**



In the above photo an engineer is transcribing test results directly into a computer using the **ScreenWriter,** a transparent tablet designed for handwriting recognition applications. Developed by MicroTouch Systems Inc., Woburn, MA, ScreenWriter consists of a glass sensor, a stylus, and a controller. The screen delivers resolution of 2048 x 2048 points, while the controller can digitize over 100 points per second. Unlike other handwriting recognition systems, ScreenWriter allows users to write directly on the display, eliminating the need for a separate graphics tablet and increasing portability.
**Circle Reader Action Number 770.**

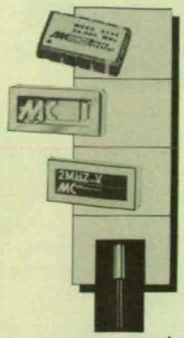
Control Vision Inc., Idaho Falls, ID, has unveiled the Model PN123 **laser-augmented video camera system** for viewing and controlling electric arc welding, laser welding, and other high-luminosity applications. The invention employs a pulsed laser light source in combination with a high-speed electronic shutter to handle the adverse lighting effects associated with intense electric arcs, plasmas, and combustion processes. While typically used as an attachment to a welding machine, the video system can also be applied to a variety of other energy-intensive industrial and laboratory processes, including ceramic fabrication, metallurgy, and combustion studies.
**Circle Reader Action Number 766.**



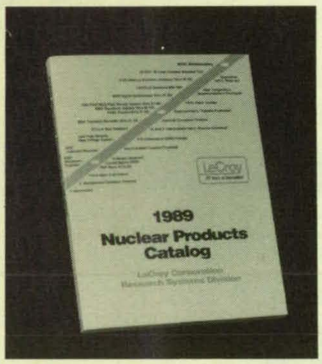
The new MC6400 Series of **attached processor boards** from Mercury Computer Systems Inc., Lowell, MA, brings supercomputing performance to microcomputer and PC workstations. Able to perform both 32-bit and 64-bit math at 20Mflops, the MC6400 serves as an application accelerator, where the user simply writes a program in C or Fortran that contains I/O statements. The program is then compiled and run on the processor without the need to write a task control program for the host. The MC6400 can also be used as a subroutine engine. In this mode of operation, a task control program running on the host calls on the MC6400 to perform computations. The subroutine can be simple, or can involve a complicated process written in higher-level languages.
**Circle Reader Action Number 760.**

The Model 1400M **video scan converter** from RGB Technology, Berkeley, CA, transforms high-resolution computer graphics to television format (NTSC or PAL), with up to 16 user-selectable workstation inputs. A dedicated image processor, the Model 1400M features 24-bit color processing, real-time operation, and sophisticated flicker filtering, and supports workstations from Sun, Apollo, Tektronix, DEC, Silicon Graphics, and IBM.
**Circle Reader Action Number 762.**

# New Literature



Miniature **quartz crystal and crystal clock oscillators** are illustrated in a new catalog from the Micro Crystal Division/SMH, New York, NY. Designed for both surface mounting and thru-hole applications, the resonators cover the 10 kHz to 35 MHz frequency range. Applications include medical products, telecommunications, instrumentation, computers, and avionics. The free catalog features various charts listing standard frequencies and calibration tolerances.
**Circle Reader Action Number 740.**

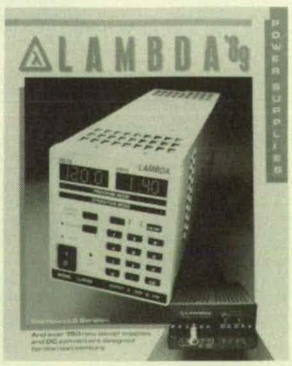



The 1989 **Nuclear Products Catalog** published by the LeCroy Corp., Chestnut Ridge, NY, illustrates LeCroy's line of electronic research instruments, including high-density data acquisition systems, fast pattern recognition/trigger electronics, and high-voltage systems. Offered free of charge, the 340-page catalog features technical data sheets, application notes, and a tutorial, complete with glossary, that provides the scientist or engineer with a base for understanding and using research instrumentation.
**Circle Reader Action Number 702.**

"**Fiber Optic Technologies And Services**," a new report from the Future Systems International Corp., Gaithersburg, MD, features a compilation of the latest advances in fiber optic technology. The report covers fiber optic applications, components, and transmission and optical switching systems. In addition, it reviews business opportunities and includes revenue projections.
**Circle Reader Action Number 724.**

The new **Optical Encoder Design Guide** from the Industrial Encoder Division of BEI Motion Systems Company, Goleta, CA, provides basic information on absolute and incremental encoder operations, explains the use of tachometer and quadrature type outputs, and describes various count multiplication techniques. Available free of charge, the guide includes a section on selecting encoders for industrial environments, a glossary of encoder terms, and application notes.
**Circle Reader Action Number 714.**


Acculex, Taunton, MA, is offering a free **Industrial Source Book** featuring a wide selection of digital panel meters (DPMs), including a battery-powered 10 KHz counter, a portable LCD voltage input DPM, and a micro-size RDT input DPM. Also described in the 64-page publication are low-cost thermocouples, pressure transducers, temperature controllers, programmable controllers, digital panel instruments, and panel mount printers.
**Circle Reader Action Number 722.**




Lambda Electronics, Melville, NY, is offering a free 200-page catalog containing specifications, illustrations, and prices for **more than 1,000 standard power supplies, power systems, and DC converters**. Among the new products featured in the catalog are remotely programmable power supplies for voltage applications up to 120 VDC, and isolated DC-to-DC converters for aerospace and other high-density uses.
**Circle Reader Action Number 706.**

The latest issue of "**Fiber Optic Testing News**," published by Fotec Inc., Boston, MA, features articles on controlling modal distribution in test launch cables and on compensating for source wavelengths. A product section covers new test kits for FDDI and CATV systems, loopback and in-line attenuators, and low-cost laser sources for loss testing. The newsletter also describes how fiber optic bandwidth is measured.
**Circle Reader Action Number 720.**


A free catalog from InfraRed Associates Inc., Cranbury, NJ, features advanced **infrared detectors**, including HgCdTe, InSb, PbSe, PbS, Ge, and pyroelectrics. Accessories such as preamplifiers, cooling systems, and temperature controllers are also described.
**Circle Reader Action Number 704.**


More than 1500 **pressure, temperature, and flow controls and gauges** are detailed in a free catalog from Dwyer Instruments Inc., Michigan City, IN. New products featured include the Dwyer Model 640 air velocity transmitter and Model 475-1 handheld digital manometer, as well as the Anderson Model H3 explosion-proof differential pressure switch. The catalog contains application notes, technical data, and reference tables.
**Circle Reader Action Number 710.**

A free brochure from Plasma Technology Inc., Torrance, CA, highlights the advantages of **plasma coating** for the automotive, aviation, marine, computer, cryogenics, and petrochemical industries. The brochure describes how a plasma is formed, explains the plasma coating process, and provides examples of applications to components such as turbine engine fasteners, automotive engine pistons, hydraulic pump wing shafts, and titanium valves.
**Circle Reader Action Number 726.**


"Shot Peening Applications," a newly revised **engineering manual** from the Metal Improvement Company Inc., Belleville, MI, provides stategies for preventing metal failures caused by fatigue, stress, corrosion, cracking, fretting, and galling. Available free of charge, the manual illustrates the process of peen forming, which is used to produce the aerodynamic contours in wing skins for commercial and military aircraft.
**Circle Reader Action Number 718.**

The **CAD/CAE systems market** will continue to grow as new, less expensive 32-bit microprocessor systems are introduced, according to a recent report by the Market Intelligence Research Company, Mountain View, CA. The report projects CAD/CAE industry revenues will double by 1994, to more than $10 billion, with unit sales surpassing the 1.5 billion mark. Included in the report are company profiles, a technology overview, and a review of industry standards.
**Circle Reader Action Number 708.**

A new line of **linear positioning tables and programmable controls** are described in a 24-page catalog from Schneeberger Inc., Bedford, MA. The linear tables are available with precision runout accuracy from 0.001 to 0.002 inches per foot of travel, are modularly constructed, and are compatible with DC stepping, servo, or linear motors. When combined with Schneeberger's SC9000 motion controller, the tables become turnkey system solutions.
**Circle Reader Action Number 712.**

A four-color brochure describes the new TurboPS™ Series **laser printers** from NewGen Systems Corp., Santa Ana, CA. Designed for CAD/CAE, desktop publishing, and other graphics applications, the printers are compatible with IBM and Apple personal computers and feature standard HP LaserJet Series II™ and Epson LQ800™ emulations, menu-based printer settings, and parallel, serial, and AppleTalk™ interfaces. The TurboPS units output complex Adobe Postscript files at 30 times the speed of other laser printers, according to the manufacturer.
**Circle Reader Action Number 716.**

# Subject Index

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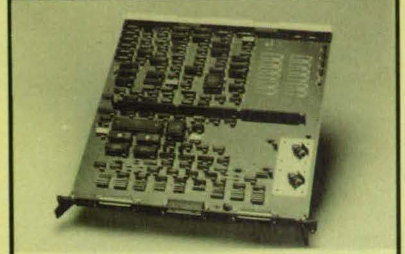

The new V/SMD 4400 Phoenix SMD disk controller from Interphase is the highest performing controller for Sun Microsystems workstations and file servers. It provides full boot support for Sun 2 and Sun 3/1XX, Sun 3/2XX and Sun 4/2XX models with OS3.X and OS4.0 and supports as many as four SMD or SMD-E drives with data transfer rates to 24 Mb/s. Intelligent multi-track caching capabilities and the speed of BUSpacket Interface improve throughput for the UNIX file system for both large and small transactions.

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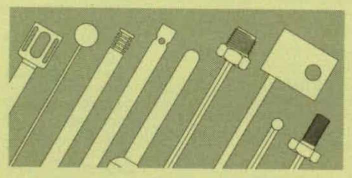

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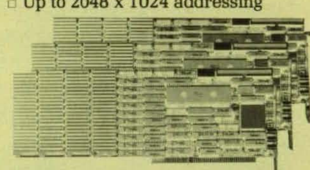

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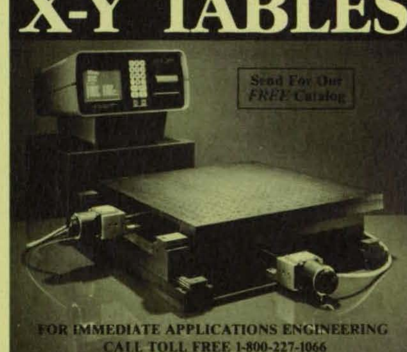

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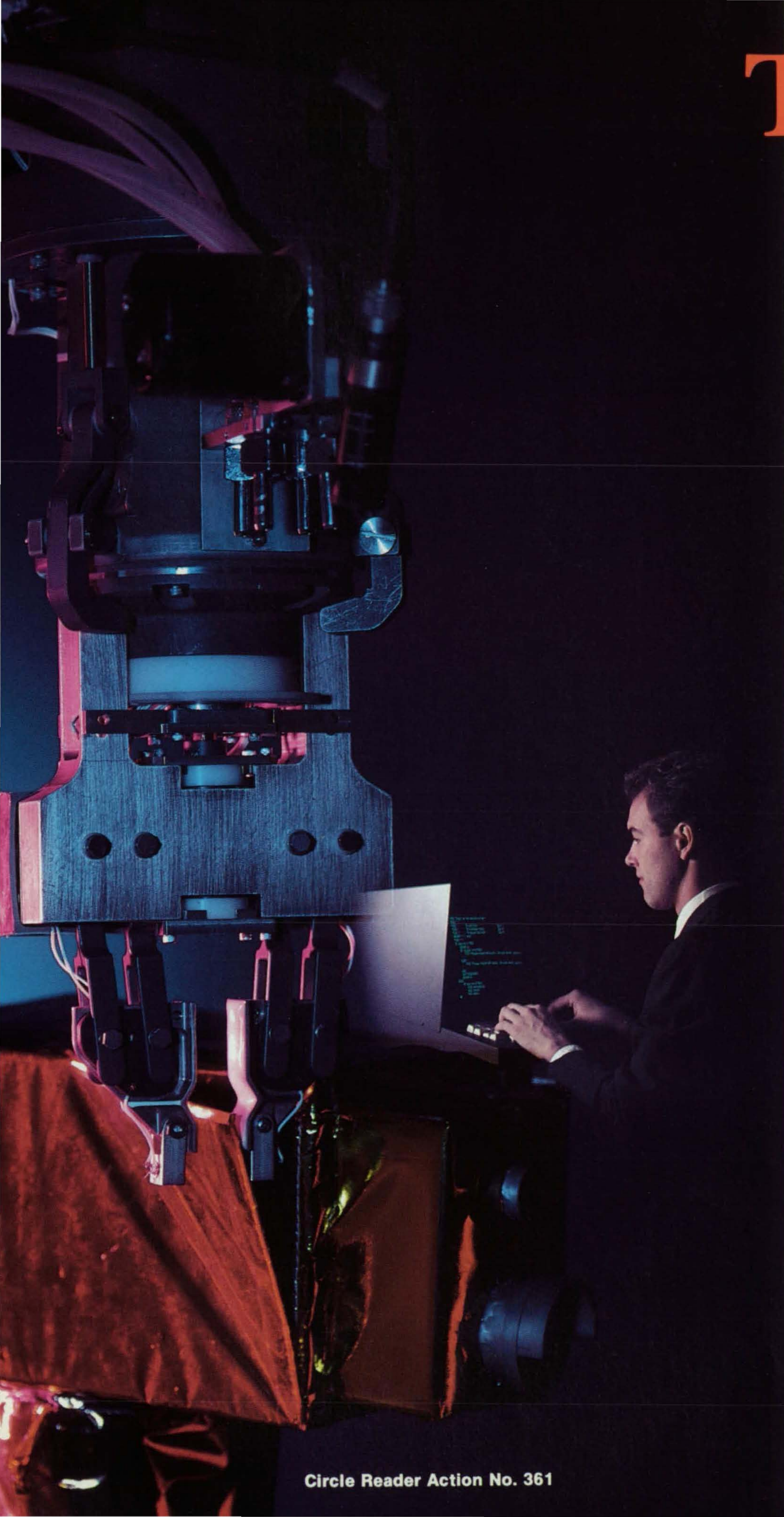

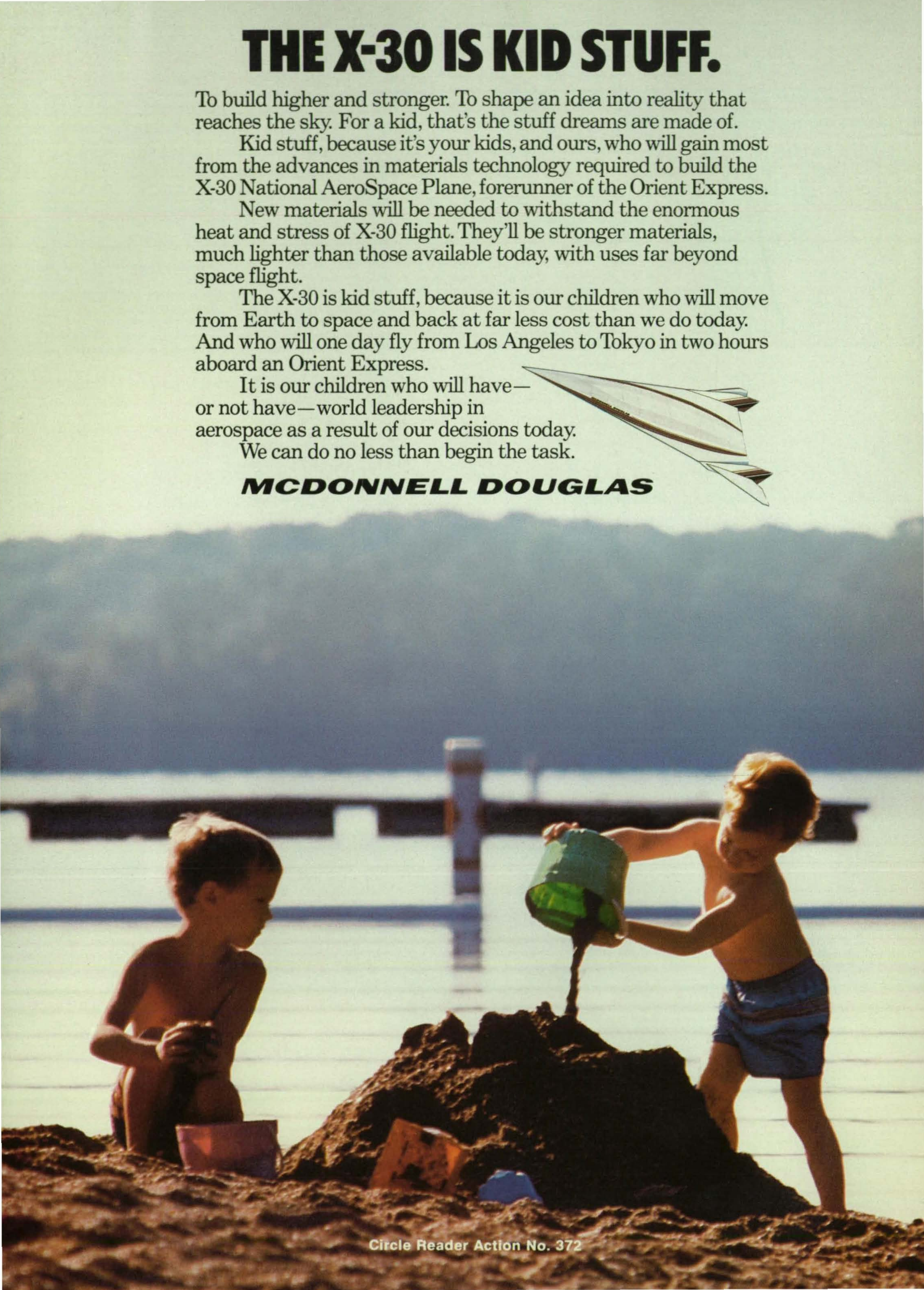
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